1

AFIT/GSO/ENS/92D-05

ANALYSIS OF TITAN IV LAUNCH RESPONSIVENESS

THESIS

Michael Timothy Dunn
Captain, USAF

AFIT/GSO/ENS/92D-05

Approved for public release; distribution unlimited

AFIT/GSO/ENS/92D-05

ANALYSIS OF TITAN IV LAUNCH RESPONSIVENESS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Space Operations

Michael Timothy Dunn, B.S.E.E.
Captain, USAF

December, 1992

Approved for public release; distribution unlimited

Thesis Approval

Student: Captain Michael T. Dunn, USAF

Class: GSO-92D

Thesis Title: Analysis of Titan IV Launch Responsiveness

Defense Date: November 25, 1992

Committee:	*Name/Title/Department*	*Signature*
Advisor:	PAUL F. AUCLAIR, Lt Col, USAF Instructor of Operations Research Department of Operational Sciences School of Engineering	Paul F. Auclair
Reader:	J. ANDREAS HOWELL, Maj, USAF Assistant Professor of Operations Research Department of Operational Sciences School of Engineering	J. Andreas Howell

Preface

The purpose of this study is to examine the potential for responsive launch operations using the Titan IV expendable launch vehicle at Cape Canaveral Air Force Station (CCAFS), Florida. My interest in space launch operations and belief that launch processing can be streamlined without degrading its integrity prompted me to explore scenarios that might result in a responsive heavy-lift launch capability for the United States using Titan IV.

During my months of research on this subject, I received assistance and support from people whose generosity with their time and talents motivated me to continue and enabled me to succeed.

There are several individuals, in addition to my classmates and family, who each deserve recognition. I thank my advisor, Lieutenant Colonel Paul F. Auclair, for his unfailing support and vision of where this research would lead us. I thank my reader, Major J. Andreas Howell, for his efforts to improve the quality of my work. I thank my sponsor, Captain Charles M. Folsom of the 45th Operations Group, and Dan Wyatt of Martin Marrietta for sharing their invaluable knowledge of Titan IV operations at CCAFS. I thank my family, especially my wife, Julie, whose support is instrumental in my life. Without these individuals, this work would not have been fulfilling personally or significant professionally.

As a note to the reader, a list of the acronyms used in this thesis is located in Appendix A.

Michael Timothy Dunn

Table of Contents

List of Figures

Figure		Page

List of Tables

AFIT/GSO/ENS/92D-05

Abstract

This research investigates the feasibility of developing responsive space systems through responsive launch operations with the Titan IV, the only expendable heavy-lift launch vehicle in the United States inventory. A definition for responsive launch has not been firmly established by Air Force Space Command for this launch vehicle. For benchmark purposes, this study uses the responsive launch definition contained in the proposal request for the Medium Launch Vehicle III: launch vehicle ignition within 60 days of mission need notification. Titan IV launch processing at Cape Canaveral Air Force Station (CCAFS), Florida currently requires in excess of six months, rendering Titan IV launch operations non-responsive.

A Top-Down analysis of Titan IV launch processing at CCAFS is conducted to expose those factors which contribute to its current total duration. The factors considered are the time required for the assembly, testing, and trans-shipment activities associated with Titan IV launch operations. Analysis of improvements in these activities estimates their effect on Titan IV responsiveness. This study indicates that a Titan IV responsive launch capability may be attainable with improvements in processing activities, with a new launch processing concept of pre-processing, or with a combination of both.

ANALYSIS OF TITAN IV LAUNCH RESPONSIVENESS

I. Introduction

The Titan IV expendable launch vehicle is the newest and largest unmanned space launch vehicle in the United States inventory. Previously referred to as Titan 34D7 or the Complementary Expendable Launch Vehicle (CELV), it is designed to carry payloads equivalent in size and weight to those carried by the Space Shuttle. Titan IV provides the United States Air Force (USAF) with a heavy-lift launch capability and is typically used to deploy payloads critical to national security. The first Titan IV launch was in 1989, and the vehicle has a perfect record of five successful launches to date.

Titan IV launch vehicles can be launched from two locations - - Cape Canaveral Air Force Station (CCAFS), Florida and Vandenberg Air Force Base (VAFB), California. The Titan IV launch processing analyzed in this thesis relates to those operations conducted at the CCAFS launch site. *Launch processing* is the generic term used to describe the sequence of activities involved in preparing a space-lift vehicle for launch. To prepare a Titan IV for launch, each of the vehicle's components are transported, integrated, and tested at various locations at CCAFS. For Titan IV, launch processing currently requires in excess of six months, with mission-specific completion times varying primarily as a function of vehicle payload. Typical payloads are heavy military satellites supporting the Defense Support Program (DSP), the Milstar communication satellite program, and other programs which are classified (16).

A definition for responsive launch has not been firmly established by Air Force Space Command for the Titan IV. For benchmark purposes, this study defers to

the definition of responsive launch contained in the proposal request for the Medium Launch Vehicle III (MLV III). The MLV III is the launch system proposed for replenishing the Global Positioning System satellite constellation and its responsiveness is defined as launch vehicle ignition within 60 days of mission need notification (13).

1.1 Overview of Current U.S. Heavy-Lift Launch Capability

The most powerful space launch vehicles in the U.S. inventory are the manned Space Transportation System (STS), also known as the Space Shuttle, and the unmanned Titan IV. These two systems comprise the heavy-lift launch capability of the United States. The payload capability of these two systems is comparable. The Space Shuttle can carry 50,200 pounds (lb) to a low earth orbit of 110 nautical miles (nm) above the surface of the Earth when launched from the Kennedy Space Center in Florida (6:D-10). The fully upgraded Titan IV can place a 47,700 lb spacecraft in the same orbit when launched from nearby CCAFS (20:268).

A clear demarcation exists between the heavy-lift class of launch vehicles and the medium-lift class, which includes the Delta and Atlas rockets. For the same orbit parameters as given above, a 110-nm orbit and the Cape Canaveral launch site, medium-lift capabilities range from 11,110 lb for the Delta II to 16,400 lb for the Atlas IIAS (6:D-2 and D-9). The "heaviest payloads in the DoD mission model" far exceed the capabilities of the medium-lift class of vehicles; only the Space Shuttle and the Titan IV launch vehicle can provide the required space-lift capability for these heavier payloads (6:17).

1.2 Responsiveness of Titan IV Launch Operations

A space-lift system places its payload into a desired orbit that is higher than low earth orbit (LEO) with a final stage booster known as an "upper stage." Titan IV heavy-lift launch operations accommodate two upper stage configurations -- the Inertial Upper Stage (IUS) and the Centaur upper stage. Regardless of upper stage configuration, Titan IV launch processing activities currently require over six

calendar months. This duration is, at a minimum, three times longer than what is required for a *responsive* launch. Thus, the Titan IV is a *non-responsive* heavy-lift launch vehicle.

The responsiveness of the Titan IV is further diminished by the unique hardware configuration of each Titan IV mission. The vehicle offers some flexibility in its ability to change payloads, even when on the launch pad, but doing so requires a considerable effort that can include changing the upper stage, the payload fairing, and even the Titan IV booster vehicle; all of which is very time-consuming. The existing launch processing of the Titan IV does not lend itself to a launch-on-demand capability. Clearly, launch processing time must be reduced if the Titan IV is to provide a responsive launch capability.

This study addresses the complex problem of reducing the Titan IV launch processing without degrading system integrity. The next chapter develops the concept of responsive launch capability and explains how it relates to Titan IV. Chapter III reviews the current Titan IV launch process and presents a summary of both critical path analysis and Top-Down analysis. A Top-Down model of Titan IV launch processing is implemented in Chapter IV with the goal of identifying which factors most contribute to the excessive duration of launch processing. Chapter V presents the Top-Down analysis of Titan IV launch operations, while Chapter VI closes the study with the conclusions and recommendations of this analysis as well as suggestions for further research.

II. *Responsive Launch Capability*

2.1 Definition

A space transportation system is said to *assure access to space* if it can place high-priority payloads in their operational orbits on demand with a high degree of confidence (30:93). The term "on demand" implies the ability to place satellites in orbit in a timely response to operational requirements. According to the *Final Report to Congress on the Conduct of the Persian Gulf War*, "The United States does not have a reactive space-launch capability, therefore replacement or augmentation of critical satellites when failures occur or crises arise is not possible" (8:K–48). As stated previously, there is no clear definition for *responsive launch* for the Titan IV. In fact, the only definition of responsive launch is contained in the proposal request for the MLV III. In the MLV III proposal request, responsive launch is defined as launch vehicle ignition within 60 days of notification of the mission need (13).

2.1.1 Background. Ambiguity in the definition of responsive launch for Titan IV can lead to misinterpretations of Air Force Manual (AFM) 2–25, *Air Force Operational Doctrine for Space Operations.* The draft of AFM 2–25 classifies the operational roles of space systems into four mission areas – – Space Control, Space Support, Force Enhancement, and Force Application (11:8–9):

- *Space Control* entails operations designed to ensure freedom of action in space for friendly forces.
- *Space Support* entails operations required to deploy and maintain military equipment and personnel in space.
- *Force Enhancement* entails space-related operations conducted to improve the effectiveness of both terrestrial-based and space-based forces.

- *Force Application* entails combat operations conducted from space for the purpose of affecting terrestrial conflicts.

The Space Support mission area includes Air Force space launch operations because it encompasses the deployment, or launching, of space systems. Launch operations are given a high priority in AFM 2–25 with statements such as the "capability to launch and deploy new and replenishment space forces is critical at all levels of conflict" (11:19). Direction is also given to space forces commanders to ensure that *responsive* launch capability is available and is well protected from hostile action (11:19). The term "responsive" is used in AFM 2–25 without definition; however, the six months for Titan IV processing would not reasonably qualify as "responsive."

2.1.2 Persian Gulf War Experience. During 1990 to 1991, Operations Desert Shield and Desert Storm highlighted the increased dependence of U.S. combat forces on military satellite systems. The coalition of nations led by the U.S. made heavy use of space-based systems in opposing Iraq's invasion of Kuwait (7:6–9). These "space-based assets were critical to many phases of the war" (7:18–2). Space-based tactical and strategic assets that provided communications, weather forecasting, and navigation assistance were utilized in what has been called the first "space war" (7:18–2).

This conflict accentuated the need for responsive space launch operations. "During Operation Desert Storm, the inability to accelerate the scheduled launch of a communications satellite demonstrated the inflexibility of the U.S. space launch capability" (7:15–2). To compensate for scarce communications satellite resources, two spare satellites were moved to support intra-theater communications (7:15–2). One of the satellites moved was a Defense Satellite Communications System (DSCS) spacecraft. DSCS is the military wide-band Super High Frequency (SHF) satellite communications system that was the principal multi-channel transmission medium

for both strategic and tactical operations in the war. To meet additional communications needs in December 1990, a reserve DSCS II was repositioned from its Pacific orbit, augmenting the primary Indian Ocean DSCS II and the East Atlantic DSCS III (8:K–32). As stated in the *Interim Report to Congress on the Conduct of the Persian Gulf Conflict*, "these recent experiences reinforce the need to make space systems more *responsive* to the tactical user" (7:15–5).

2.2 Issues Related to Responsive Launch

As seen in the Persian Gulf War, the U.S. needs space systems that quickly respond to dynamic operational requirements. In the event of conflict, space assets that support specific war-fighting mission requirements can be assured in one of two ways: by replacement through responsive launch or by relying on robust satellites.

2.2.1 Satellite Reliability, Survivability, and Maneuverability. A satellite is responsive to a user if it performs its intended function in a timely manner for its ultimate customer. Robust satellites, those with higher reliability, survivability, and maneuverability, are, by this definition, more responsive to end-users. In the event a satellite fails, is destroyed, or was never deployed, responsiveness refers to how quickly the operational users' needs can be met.

In the absence of responsive launch, an available satellite could be moved from its present position to a crisis area to fulfill the need of an end-user, as in the case of the DSCS satellite maneuver during the Persian Gulf War. However, such a satellite move is not a universal remedy. First, the satellite uses its on-board maneuvering fuel to make the move, decreasing its useful lifetime. Due to the lack of an on-orbit satellite refueling capability, once fuel is spent, the spacecraft's lifetime is reduced. Second, the previous coverage of the repositioned satellite is lost. If the satellite is moved back to its original position after the crisis, then on-board fuel is expended, causing an even greater reduction in the satellite's lifetime. Third, the

mission planning time required to coordinate a spacecraft move limits the degree of responsiveness attained solely through maneuverability.

A responsive launch of a replacement spacecraft could fill one of the vacated coverage areas even after a satellite repositioning, but such an "after-the-crisis" responsive launch operation may be of limited use depending on the user's post-emergency requirements. Clearly, space system responsiveness depends on satellite reliability, survivability, and maneuverability as well as launch responsiveness.

2.2.2 Risks of Reducing Launch Processing Duration. In order to evaluate the benefits of responsive launch, the disadvantages and risks of reducing launch processing duration must be thoroughly analyzed. A commonly accepted belief is that reducing launch processing time may potentially increase the probability of a launch failure. However, an examination of the space program of the former Soviet Union suggests otherwise.

Current U.S. space management practices result from a launch operations philosophy that emphasizes long-lived, expensive payloads; high-performance launchers; very high reliability; and low launch rates. The former Soviet Union, on the other hand, has relied on relatively inexpensive, short-lived satellites; reasonably reliable vehicles; and very high launch rates. As a result, the Soviet launch infrastructure is more resilient than that of its U.S. counterpart, although not necessarily more effective at accomplishing national goals (30:7). In fact, the Department of Defense states in the 1989 issue of *Soviet Military Power* that "the Soviets have the world's largest and most responsive space launch infrastructure" (10:54).

The Soviets have maintained their responsive launch posture with low failure rates. Of 76 known launch attempts in 1990, only two, or 2.6%, failed to deliver the payload to the desired orbit (21:6). Also, during the period from 1985 to 1989, the Soviets have acknowledged 258 launches of which only five failed, yielding a failure rate of just 1.9% (21:9).

The U.S. is now in the difficult position of attempting to retain its high-technology, high-performance approach to payloads and vehicles while attaining Soviet-style routine access to space. This goal is probably unattainable unless the U.S. substantially alters the way it conducts space transportation operations (30:7).

2.3 Importance of Titan IV

One way of attaining responsive space systems is through responsive launch operations with vehicles such as the Titan IV. The U.S. Department of Defense space policy states that expendable launch vehicles are the primary launch vehicles for national security payloads that do not require a man in space (9:4). Because Titan IV is the main heavy-lift expendable launch vehicle for the United States, this launch system plays an important role in its national security.

The *System Operational Requirements Document (SORD) for Titan IV* lists the primary operational requirement for Titan IV as providing "assured access to space for selected DoD shuttle class payloads from CCAFS and VAFB" (3:4). More importantly, Titan IV is the sole launch vehicle capable of using the Centaur G–Prime upper stage. This upper stage is the only U.S. vehicle capable of placing payloads in excess of 10,000 lb into geosynchronous orbit. In contrast, the Space Shuttle with the Inertial Upper Stage is limited to a payload of roughly 5,000 lb for this orbit. Thus, for the high-priority payloads carried by the Titan IV, a responsive launch capability would be advantageous to U.S. interests. The importance of the Titan IV is also demonstrated by the Air Force's plan to purchase nine Titan IV launch vehicles in addition to the 41 vehicles currently on contract (14).

2.4 Factors Contributing to Titan IV Non-Responsiveness

There are historical, technical, and motivational factors that contribute to current Titan IV non-responsiveness. The desire to avoid another space launch disaster following the *Challenger* explosion and the shift of space launch responsibility

between USAF major commands have been powerful influences on U.S. space launch responsiveness.

2.4.1 Unacceptability of Launch Failure. The highly conservative posture predominant in the space launch field today is a result of the Space Shuttle *Challenger* disaster and ensuing Rogers Commission investigation of 1986, the two Titan 34D launch failures of August 1985 and April 1986, and the Delta and Atlas failures of 1986 and 1987. Glenn Wilson, the former Executive Director of the National Space Society, describes the situation by saying "All the bolt-by-bolt investigation of the Rogers Commission seems to have accomplished is to force us into a posture that says every space venture must be 100 percent risk-free before we will consider it" (32:3). Excessive conservatism in Titan IV launch operations could preclude the attainment of a responsive launch capability.

The time it takes to integrate, test, and launch space-lift vehicles is much greater now than before the Titan and Shuttle failures. Increased emphasis on detecting potential failures contributes most to extending the duration of launch processing activities (30:27). Extreme caution is exercised in assuring that each Titan IV performs successfully upon launch. Much of this caution stems from the expense of Titan's payloads, which generally cost hundreds of millions of dollars (24:33). According to one congressional source, the Air Force acts prudently in minimizing the risk of a launch disaster with costly payloads. This source states "You'd weep if you knew how expensive some of those things (payloads) are" (22:28).

2.4.2 Operational versus Developmental Perspective. Current Titan IV operations at CCAFS are conducted by the Astronautics Group of Martin Marietta under the direction of the Titan Combined Test Force (CTF), 45th Operations Group, 45th Space Wing. Staffed with personnel from Air Force Materiel Command (AFMC) and Air Force Space Command (AFSPACECOM), the CTF was chartered to transition

Titan IV operations from AFMC to AFSPACECOM. Martin Marietta serves as the prime contractor for the Titan IV launch vehicle program.

The conservative posture of the former Air Force Systems Command (AFSC), under which launch operations were conducted until 1990, contributes to Titan IV non-responsiveness. The developmental approach to launch operations by AFSC emphasized mission success without regard to time or cost considerations. By way of contrast, an operations approach to launch processing simultaneously considers responsiveness, cost, and likelihood of mission success in routine operations planning.

Air Force Space Command assumed responsibility for all Air Force space launch operations in 1990. According to then-commander of AFSPACECOM, Lieutenant General Thomas Moorman, "Transferring launch operations from Air Force Systems Command to this command is a natural evolution of space activities from the research-and-development environment to the operational arena." AFSPACECOM strives to inject operational priorities and efficiencies into launch systems (1:15). Unfortunately, this philosophy has yet to be incorporated in Titan IV launch operations at CCAFS (17).

Launch operations tend to be complex and time consuming because vehicles have been designed to achieve high performance rather than rapid, inexpensive launch turnaround. Furthermore, launch managers perceive that they can improve the chances of launch success by repeatedly testing every possible subsystem before launch (30:26). AFSPACECOM desires more operable launch systems with far greater standardization than current systems. The goal of future launch systems is to permit launch only a few days after a call for launch is made rather than the weeks or months required by current systems (25:8). General Charles A. Horner, Commander-in-Chief of U.S. Space Command, stated that standard designs must replace custom-built, one-of-a-kind payloads and that timely launches should be conducted by trained crews using checklists, rather than by engineers with their "test-as-you-go" processes (12:30).

Titan IV launch processing currently consists of two primary types of activities - - assembly and testing. Assembly activities include the actual mechanical and electrical integration of the Titan IV launch vehicle and its mating to the payload. The testing process is a series of detailed tests of all elements of the vehicle to ensure proper functionality and safety. Testing of individual components or subsystems begins during assembly. Testing of the integrated Titan IV occurs on three separate occasions during the launch processing sequence. Approximately half of the total processing time among those activities that define the duration of launch processing is devoted to testing, much of which is redundant.

The unique configuration of each Titan IV mission further contributes to its non-responsiveness. Engineers at Martin Marietta are concerned that irreparable damage to one-of-a-kind components or to components with few spares might result if the vehicle is not tested at many levels (37). These components could be damaged by other installed subsystems that might "stress" the unique piece if not adequately tested.

2.4.2.1 Incentives and Goals. While the testing procedures and the research and development (R&D) philosophy are primary contributors to Titan IV non-responsiveness, there are two other less tangible, but significant factors that contribute to this posture. One is the Titan IV contract incentive structure, and the other involves Martin Marietta's economic goal.

Measures and incentives often determine behavior. Providing the proper incentives is not a simple problem for the Air Force or for any private company. As noted by Norman Augustine, Chairman and CEO of Martin Marietta Corporation, "Incentivizing is one of the central problems in acquisition" (4). Monetary incentives and award fees may have a strong influence on Martin Marietta's Titan IV operations. For example, Martin Marietta earns a handsome incentive fee for a successful launch,

but relatively modest award fees for performance in such areas as management and technical merit. The launch processing schedule is not tied to the incentive fee (31).

For the first 23 Titan IV launches, an incentive fee is paid to the prime contractor from an incentive pool. A similar incentive structure is planned for the 24th and following missions (31). The total incentive pool for the first 23 launches is roughly $161 million, or around $7 million per successful launch. A successful launch is defined as one that satisfies the program director that the payload was successfully inserted into the desired orbit (31). Conversely, for launch failure, there is a negative incentive of 6.25 times the positive incentive per launch, or about $44 million per launch failure (31). The contractor does not pay this fee; it is simply deducted from the incentive pool, reducing the amount available for future incentives.

The current incentive structure does not reward the performance of Martin Marietta in the area of launch responsiveness. The incentives motivate the prime contractor toward absolute mission success at the expense of responsive launch. The current institutional management structure tends to heavily penalize launch failure, but is poorly structured to reward increases in launch rate (30:8). "There is the incentive not to fail," observed one worker in the space launch community (30:20).

Martin Marietta is paid each year for a "level of effort," not for its services on a per launch basis (31). In effect, the Air Force pays for a standing army of launch personnel each year. This army of technicians and engineers is paid the same amount per year regardless of the number of Titan IV launches. The only money in addition to that paid for the yearly services consists of the previously described incentives. This arrangement has the effect of rewarding Martin Marietta solely for individual launch successes without regard to the aggregate launch rate.

It must be pointed out that Martin Marietta is meeting the contract and is performing exactly to Air Force specifications in the Titan IV contract. Martin Marietta is strongly motivated by the reward structure to achieve successful launches without regard to responsiveness. Review of the incentive and payment structure

suggests that launch responsiveness is not an Air Force priority. The Titan IV program incentives appear to be heavily influenced by a research and development perspective. A different incentive structure will be needed if the Air Force seeks to encourage responsive launch.

The Titan IV incentive package motivates Martin Marietta, the prime contractor, toward a goal that may not match that of the Air Force. The goal of Titan IV launch operations for the Air Force is to place heavy, high-priority satellites into orbit accurately, economically, and responsively. However, Martin Marietta's goal may not correspond to that of the Air Force. The corporation's *stated* goals for the Titan IV program could be to:

- Provide jobs.
- Develop leading-edge technology in expendable launch vehicles.
- Produce a launch vehicle of "engineering excellence."

Although the above items are *purposes* of Martin Marietta's Titan IV operations, in actuality, they do not represent the corporation's *goal*. The goal of Titan IV launch operations for Martin Marietta is to make money both now and in the future (18:40). It is interesting to note that the goal for Titan IV launch operations as viewed by the Air Force and Martin Marietta is different. This conflict in goals could contribute to the non-responsiveness of the Titan IV as an expendable launch vehicle.

2.5 Summary

The ultimate mission of an on-orbit space system is to support the end-user of that particular satellite. For crisis situations, sustained operations of satellites is assured by one or a combination of two ways - - robustness or replacement. Robustness requires a higher degree of satellite reliability, survivability, and maneuverability. Replacement through responsive launch requires a space launch capability that is much more reactive than today.

If prompt satellite replacement through responsive launch is desired, then certain issues must be addressed. AFM 2-25 states a validated need for a responsive launch capability (11:19). The recent experiences of the Persian Gulf War demonstrate this need. However, current U.S. space launch systems, particularly Titan IV, fail to qualify as responsive. There are several reasons for Titan IV's non-responsiveness. Among them are the demand for absolute mission success and the resulting caution in space launch. The recent change of responsibility for launch operations from the former Air Force Systems Command to Air Force Space Command has accentuated the need to change from the research and development posture to one with a more operational orientation. The current incentive structure in the Titan IV contract also inhibits responsiveness. If the Air Force truly seeks responsive space launch launch systems, then the contracts and associated incentives must be written to reflect this desire.

III. Background

This chapter contains background information for three areas of interest in this research - - the Titan IV vehicle and its launch processing, critical path analysis, and Top-Down analysis. The first section describes the launch vehicle and the processing performed at CCAFS, while the last two sections discuss methods used to analyze the problem.

3.1 Titan IV Launch Operations Overview

Current Titan IV operations at CCAFS are conducted by Martin Marietta under the direction of the Titan Combined Test Force (CTF), 45th Operations Group, 45th Space Wing. Staffed with personnel from Air Force Materiel Command (AFMC) and Air Force Space Command (AFSPACECOM), the CTF was chartered to transition Titan IV operations from AFMC to AFSPACECOM.

Martin Marietta is the prime contractor for the Titan IV program and is under contract with the USAF to provide 41 Titan IV vehicles and associated launch services (19:36). The total cost of the current Titan IV program's contract is $8.5 billion (23:20). Launch facilities for the Titan IV include two separate launch pads at CCAFS and one pad at VAFB.

3.1.1 The Titan IV Launch Vehicle. Titan IV, produced and launched for the USAF by the Astronautics Group of Martin Marietta, is the nation's largest, most powerful expendable space launch vehicle. It was designed to complement the Space Shuttle and provide assured access to space for the United States. The Titan IV is the newest vehicle in the Titan family produced by Martin Marietta. It has evolved from the Titan I Intercontinental Ballistic Missile (ICBM), which first flew in 1959 (19:34). The fully integrated Titan IV launch vehicle shown in Figure 3.1 consists of the following five majo: ements (34:6):

1. A liquid propellant two-stage core vehicle consisting of Stages 1 and 2.
2. A 16.7-foot (ft) diameter payload fairing.
3. The possible addition of an upper stage depending on the payload requirement.
4. Two solid propellant motors called Stage 0.
5. The satellite payload.

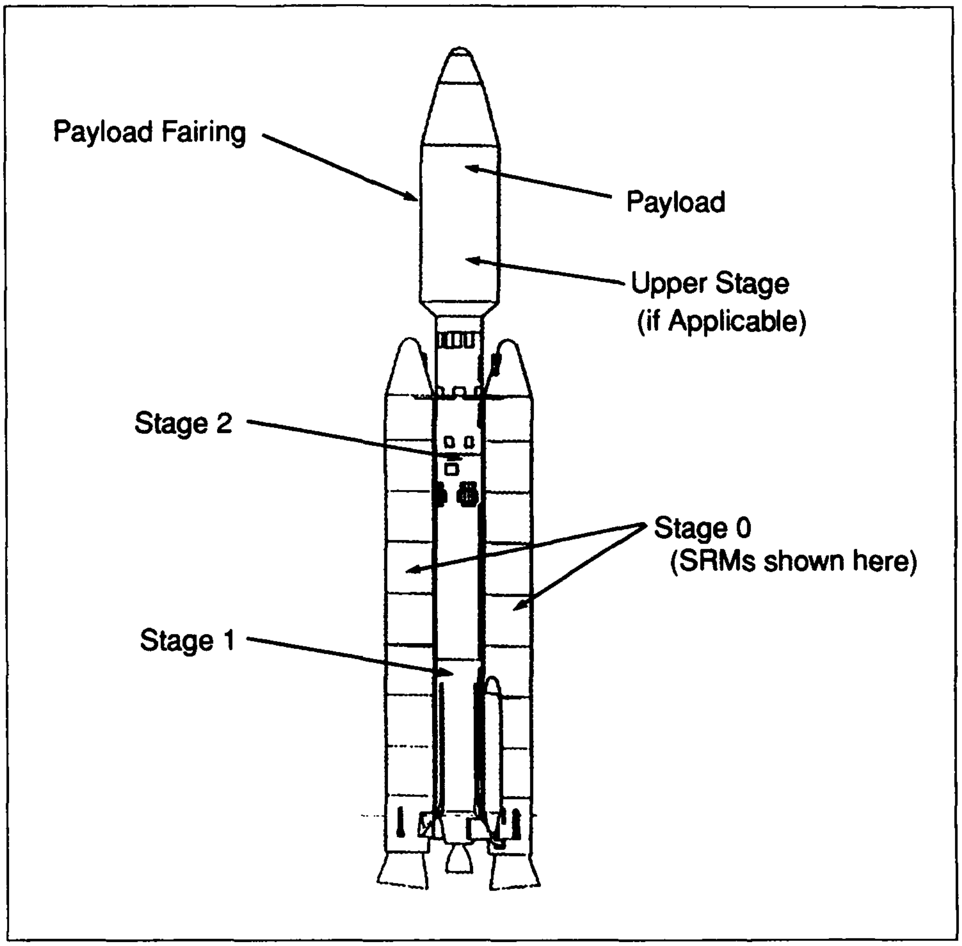

Figure 3.1. The Titan IV Launch Vehicle.

3.1.1.1 The Core Vehicle. The "core vehicle" (CV) consists of Titan's two liquid-propellant stages, referred to as Stage 1 and Stage 2. In addition to

providing part of Titan IV's boost capability, the core vehicle serves as a chassis onto which all of the other major elements of the launch system are attached.

Stage 1 contains an Aerojet LR87–AJ–11 engine that provides an average thrust of 548,000 lb. The average specific impulse of Stage 1 is 302 seconds (sec). Stage 2 consists of one Aerojet LR91–AJ–11 engine rated at 105,000 lb of average thrust with an average specific impulse of 316 sec (20:270–271). More detailed information concerning the two liquid stages of the core vehicle is shown in Table 3.1.

Table 3.1. Titan IV Core Vehicle (Stages 1 and 2) Characteristics (20:270–271).

Parameter	**CV Stage 1**	**CV Stage 2**
Manufacturer	Aerojet	Aerojet
Engine Designation	LR87–AJ–11	LR91–AJ–11
Number of Subassemblies	2	1
Length	86.5 ft	32.7 ft
Diameter	10.0 ft	10.0 ft
Gross Mass	359,000 lb	87,000 lb
Propellant Mass	340,000 lb	77,200 lb
Structural Material	Aluminum	
Propellant	Liquid (N_2O_4–Aerozine 50)	
Average Thrust (vacuum)	548,000 lb	105,000 lb
Specific Impulse (vacuum)	302 sec	316 sec
Thrust Vector Control	Hydraulic Gimballing (2 nozzles)	Hydraulic Gimballing and Gas Generator Exhaust
Nominal Burn Time	190 sec	223 sec

3.1.1.2 The Payload Fairing. The Titan IV uses four different payload fairings that cover and protect the spacecraft and upper stage during launch. The payload and upper stage are delicate pieces of equipment and require protection from contaminants and moisture in the atmosphere as well as dynamic pressure changes. The appropriate fairing depends upon the size of the payload and whether an upper stage is used. To accommodate a variety of payloads, each fairing has a

diameter of 16.7 ft and a length of either 56, 66, 76, or 86 ft. Detailed payload fairing information is listed in Table B.5 in Appendix B. Although alternative Titan IV configurations provide versatility, they impede operational responsiveness due to the mission-unique modifications required for each fairing. Presently, every Titan IV has a unique configuration, but current plans dictate less customization of vehicles after the 24th Titan IV mission.

3.1.1.3 The Upper Stage. There are three upper stage configurations compatible with Titan IV payloads - - the Inertial Upper Stage (IUS), the Centaur upper stage, and a configuration with "No Upper Stage" (TIV/NUS) above Stage 2 of the core vehicle (34:7). The Titan IV with IUS (TIV/IUS) can place 5,250 pounds (lb) in geosynchronous orbit while with the Centaur upper stage (TIV/Centaur) can place almost twice that amount into the same orbit. The version of the Centaur used by Titan IV, the Modified Centaur G–Prime, is currently the most powerful upper stage in the American inventory. It is a single-stage cryogenic pressure-stabilized vehicle consisting of two Pratt & Whitney RL10A–3–3A restartable liquid motors.

Detailed specifications for the IUS and the Centaur upper stage are shown in Table 3.2. Note the use of the solid propellant Hydroxy Terminated Polybutadiene (HTPB) in the IUS versus liquid oxygen and hydrogen in the Centaur. The Centaur restartable engines offer an advantage over the solid, one-burn IUS motors. Complete information on the Titan IV payload capabilities for its different configurations is shown in Table B.2 located in Appendix B.

3.1.1.4 The SRMs and the SRMUs. The lift-off thrust of the Titan IV is provided solely by its two solid rocket motors which can be either the Solid Rocket Motor (SRM) or Solid Rocket Motor Upgrade (SRMU) boosters (20:269). Two of either of these motors constitute what is called "Stage 0."

Each SRM consists of seven 10-ft segments plus forward and aft closures. The other solid rocket motor, the SRMU, is a newer design than the SRM. Pertinent

Table 3.2. Upper Stage Characteristics (20:271).

Parameter	IUS		Centaur
Manufacturer	Boeing		General Dynamics
Length	·17 ft		29.5 ft
Diameter	9.5 ft		14 ft
	Stage 1	Stage 2	
Gross Mass	23,960 lb	8,600 lb	52,600 lb
Propellant Mass	21,400 lb	6,060 lb	44,800 lb
Propellant	Solid (HTPB)	Solid (HTPB)	Liquid (O_2/H_2)
Average Thrust (vacuum)	45,000 lb	18,300 lb	33,000 lb
Specific Impulse (vacuum)	292.9 sec	300.9 sec	444 sec
Nominal Burn Time	153 sec	104 sec	600 sec (restartable)

information about both the SRM and the SRMU is summarized in Table 3.3. The upgraded solid rocket motors provide Titan IV with an increased payload capability and also enhance the program's flexibility and reliability by having two separate types of solid boosters. The USAF currently has contracted for 15 flight sets of SRMUs, where one flight set consists of two SRMUs.

The SRMU is a filament-wound composite case and is different than the more conventional steel case of the SRM. The use of composite material reduces the case weight of the rocket motor from 96,000 lb to 81,000 lb while increasing case strength. Case weight includes the motor casing itself and all associated solid rocket motor subsystem components. The lower weight and greater strength allow an additional 88,000 lb of propellant to be used in each upgraded motor versus the standard SRM (20:269). This improvement results in an increase in the vehicle's payload capability of approximately 25%.

Other key differences between the SRMU and the SRM are the number of segments per booster and the type of propellant used. The SRMU has only three

Table 3.3. Titan IV Solid Rocket Motor (Stage 0) Characteristics (20:269).

Parameter	**SRM**	**SRMU**
Manufacturer	United Technologies	Hercules
Length	112 ft	112.4 ft
Diameter	10.2 ft	10.5 ft
Number of Motors	2	2
Number of Segments	7	3
Gross Mass	696,000 lb	769,000 lb
Propellant Mass	600,000 lb	688,000 lb
Case Material	Steel	Graphite
Propellant	Solid (84% PBAN)	Solid (88% HTPB)
Average Thrust (each) (vacuum)	1.6 million lb	1.7 million lb
Specific Impulse (vacuum)	271.6 sec	285.6 sec
Thrust Vector Control	N_2O_4 Liquid Injection	Hydraulic Gimballing
Nominal Burn Time	121.5 sec	137.8 sec

segments per booster compared to seven for the SRM. The upgraded motor uses Hydroxy Terminated Polybutadiene (HTPB) while Polybutadiene Acrylonitrile Acrylic Acid (PBAN) is used in the SRM(20:269).

A diagram of a Titan IV typical flight sequence is shown in Figure B.2 located in Appendix B. Also included in Appendix B is Table B.6 that lists the time and altitudes of the launch sequence events.

3.1.2 Titan IV Launch Processing Activities. Before a specific description of Titan IV launch processing is provided, a general overview of a generic launch process is helpful. To boost a satellite into orbit using any expendable launch vehicle, the following activities must be performed in this given sequence:

1. Perform initial launch vehicle construction at the vehicle component manufacturers' plants.

2. Conduct initial vehicle and avionics acceptance testing at the manufacturing facilities.

3. Ship the launch vehicle and components to the launch site.

4. Erect the launch vehicle and integrate the vehicle with its payload.

5. Perform testing of the integrated vehicle at the launch pad.

6. Fuel the launch vehicle and perform final verification tests prior to launch.

The launch processing area for Titan IV at Cape Canaveral Air Force Station is called the "ITL Area." ITL is an acronym for the launch processing concept of Integrate/Transfer/Launch. ITL consists of the following actions: *Integrate* the major components of the launch vehicle and the spacecraft payload, *transfer* the hardware between processing facilities, and *launch* the integrated vehicle. The ITL technique of launch processing minimizes the amount of time the vehicle must remain on the launch pad (30:35).

Facilities of the ITL Area are shown in Figure 3.2. They include the Vertical Integration Building (VIB), the Solid Rocket Motor (SRM) Segment Processing buildings, the Solid Motor Assembly Building (SMAB), the Solid Motor Assembly and Readiness Facility (SMARF), and the two launch pads: Space Launch Complex (SLC) 40 and SLC–41. The Titan IV vehicle is transferred between facilities via railway on one of three Titan IV transporters. The transporter provides a platform for the Titan IV launch processing activities as well as lift-off itself.

Specifically for Titan IV launch processing, the final three steps of processing a generic launch vehicle are performed at CCAFS and consist of the following items:

- Core vehicle assembly and liquid rocket engines mate and testing.
- Solid motor segment inspection and assembly.
- Payload fairing cleaning and preparation.

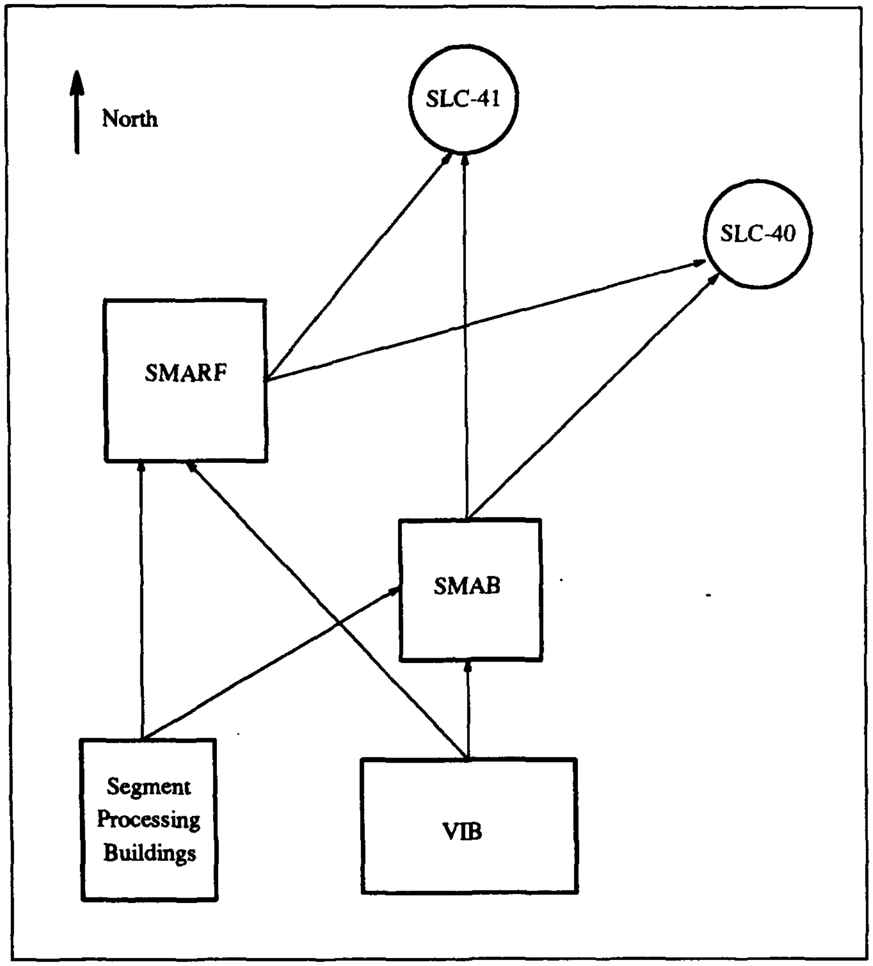

Figure 3.2. Integrate/Transfer/Launch (ITL) Area at CCAFS

- Upper stage avionics assembly and testing.
- Payload preparation.
- Mating and integrated testing of all major elements.

A diagram of the serial flow of activities of Titan IV launch processing is shown in Figure 3.3. The tasks necessary to prepare a Titan IV vehicle for launch are described in the following sections as they relate to the facilities of the ITL Area.

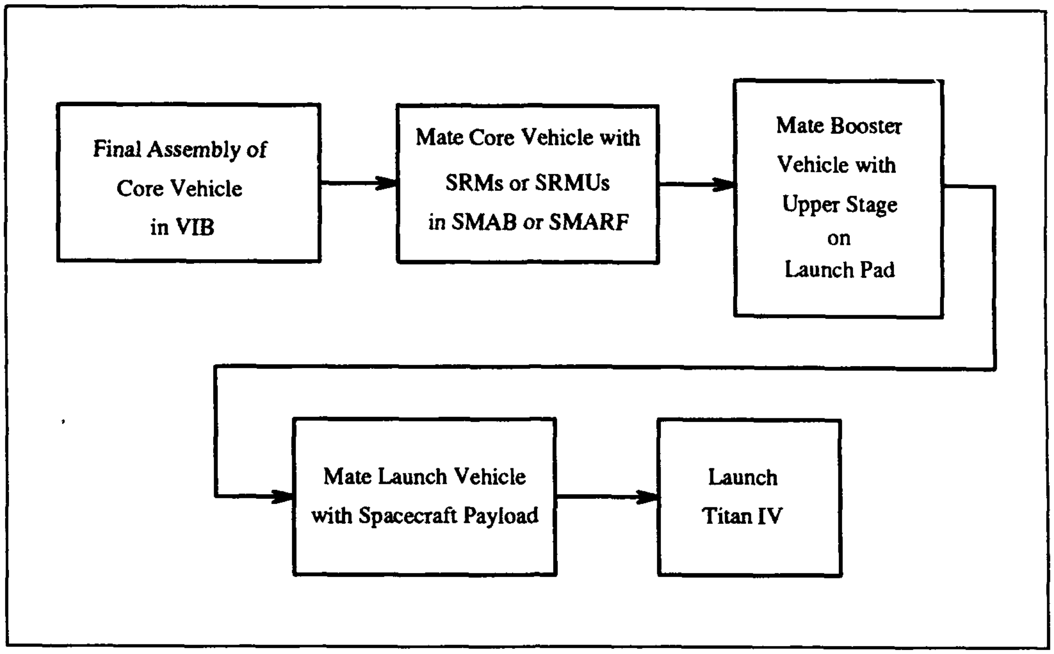

Figure 3.3. Titan IV Launch Processing Flow.

3.1.2.1 Vertical Integration Building (VIB) Activities. Titan IV launch processing begins with the parallel activities of transporter refurbishment and final assembly of the core vehicle. Transporter refurbishment occurs in an open area near the VIB and includes cleaning from the previous launch and applying a protective substance, Martyte, to the structure. Martyte is used for heat and flame retardancy to limit damage to the transporter during lift-off. Transporter preparation is complete when the transporter is mated to a van set and the electrical systems functional test is performed.

Core vehicle final assembly activities occur concurrently in the Low Bay of the VIB. Figure 3.4 shows a diagram of the VIB layout. Vertical processing cells available for Titan IV are VIB Cells 2 and 4. VIB Cell 1 is reserved for the processing of Martin Marietta's Commercial Titan (CT) launch vehicle. Note the Centaur upper stage's processing area located in VIB Cell 3. It is designated on the diagram as

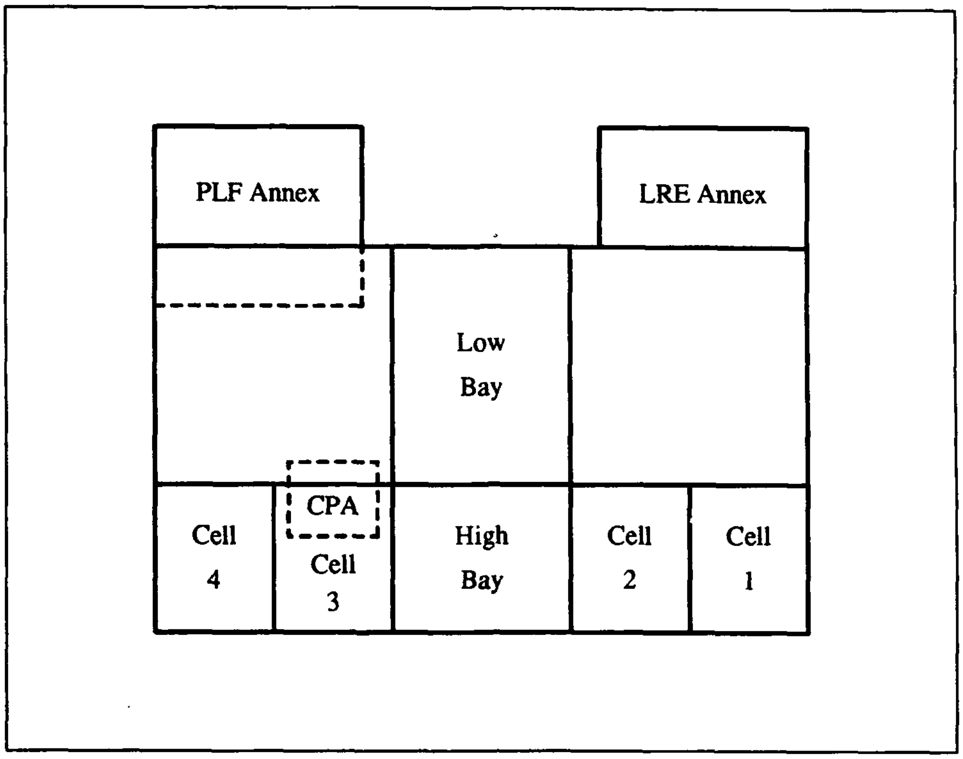

Figure 3.4. Layout of the Vertical Integration Building (VIB) (34:6).

CPA. Note also the VIB Payload Fairing (PLF) Annex and the VIB Liquid Rocket Engine (LRE) Annex.

Martin Marietta performs most of the core vehicle's final assembly at Cape Canaveral rather than at the factory in Denver, Colorado (30:35). Final assembly activities include installation of liquid rocket engines, electronic components, and hydraulic systems. Following assembly of the core vehicle, its weight is measured and verified to set flight parameters.

The liquid rocket engines are attached to the fuel and oxidizer tanks of Stages 1 and 2. After the engines are mounted and VIB Low Bay work is completed, Stage 1 is erected in the vertical position and placed on the transporter in one of the two Titan IV VIB processing cells. Stage 2 is then erected and mated with Stage 1. The transporter vehicle and associated van set remain with the Titan IV vehicle through

its launch. The van set enables the rocket to communicate with the Programmable Aerospace Control Equipment (PACE) which is used to test and launch the Titan IV.

With the core vehicle erected, umbilical connections are made and initial power is applied. Numerous tests are performed on the following core vehicle subsystems: tracking and flight safety, instrumentation, flight controls, guidance, electrical, and propulsion. A final integrated test called the Combined Systems Test (CST) is performed on the core vehicle in the VIB cell prior to further launch processing. The CST is a complete countdown and count-up of all Titan IV launch vehicle systems and is controlled by the PACE. Once the CST is complete, the core vehicle is moved in the vertical position on the transporter via rail to the SMAB or the SMARF.

3.1.2.2 Parallel Activities. Concurrent with core vehicle processing in the VIB, four other components are simultaneously processed in other facilities of the ITL Area. These components are the payload fairing, the upper stages, some payloads, and the SRM or the SRMU segments.

Payload fairing processing activities occur in the VIB Payload Fairing Annex. These activities include cleaning, applying thermal coating, installing acoustic blankets and instrumentation, and verifying electrical continuity. The payload fairing is transported to the launch pad and is used to encapsulate the upper stage and payload except for missions with the Centaur where the base module of the payload fairing is attached to the upper stage prior to its arrival at the launch pad.

Upper stage processing activities for both the IUS and the Centaur are performed concurrently with the core vehicle. The IUS processing facility is located in the East Bay of the SMAB. Figure 3.5 shows the layout of the SMAB. The Centaur upper stage processing area is VIB Cell 3 as shown previously in Figure 3.4.

Activities for the upper stages include installation and testing of flight components and performance of system tests. The Centaur is a very complex space vehicle

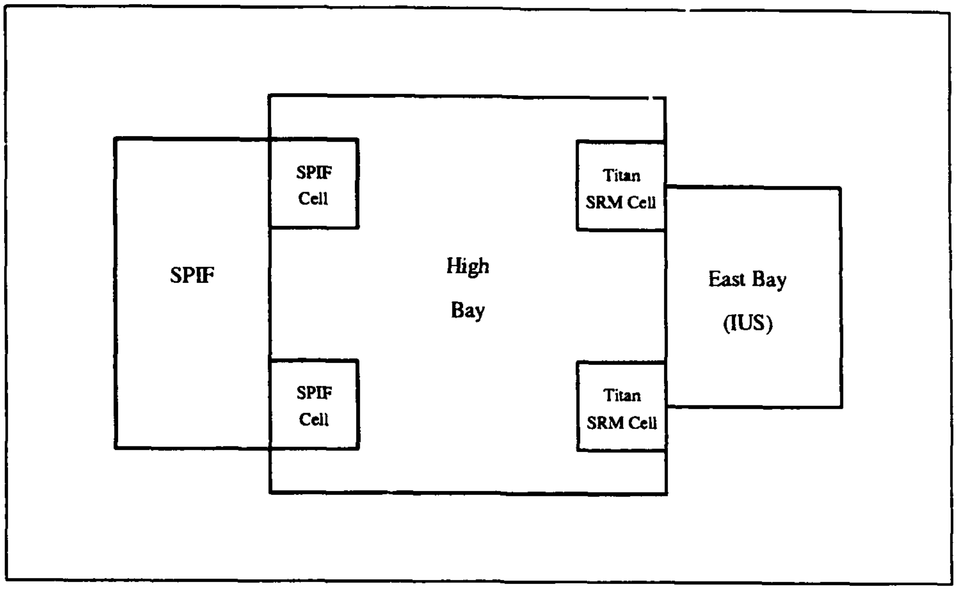

Figure 3.5. Layout of the Solid Motor Assembly Building (SMAB) (34:2).

and requires 45 working days to process in VIB Cell 3 (35). Once assembled and tested, it is encapsulated with the base module of the payload fairing and then stored on the floor of VIB Cell 3 until it is needed at the launch pad (34:8). The upper stage, either IUS or Centaur, is transported to the launch pad upon completion of core vehicle mating with the solid rocket motors.

Some Titan IV payloads are processed for launch in the ITL Area while others are processed outside of this area. Details of payload processing are outside the scope of this research and therefore are not addressed.

3.1.2.3 SMAB and SMARF Activities. The following discussion applies to Titan IV missions that use a pair of SRMs as Stage 0. The solid rocket motor segments arrive at the Cape via rail transportation. They undergo individual inspection and non-destructive testing in the segment processing buildings of the ITL Area prior to assembly. SRM non-destructive testing consists of x-ray, ultrasonic,

and laser video testing of the segments. It requires 65 working days to complete (35).

After non-destructive testing, the segments are transported to the SMAB for assembly. The segments are stacked to form the SRMs in the two Titan SRM Cells. Note that in Figure 3.5 the Shuttle Processing Integration Facility (SPIF) now occupies two of the original four Titan SRM Cells. Due to crane limitations in the SMAB, only the bottom five segments are stacked for each SRM. After stacking two sets of five segments in the cells, the core vehicle arrives on its transporter from the VIB for mating with the SRMs in the High Bay. After mating, this assembly is transported to one of the two launch pads.

For a Titan IV mission using SRMUs, the segments are shipped to the SMARF via rail from the manufacturer. A diagram of the SMARF is shown in Figure 3.6. The

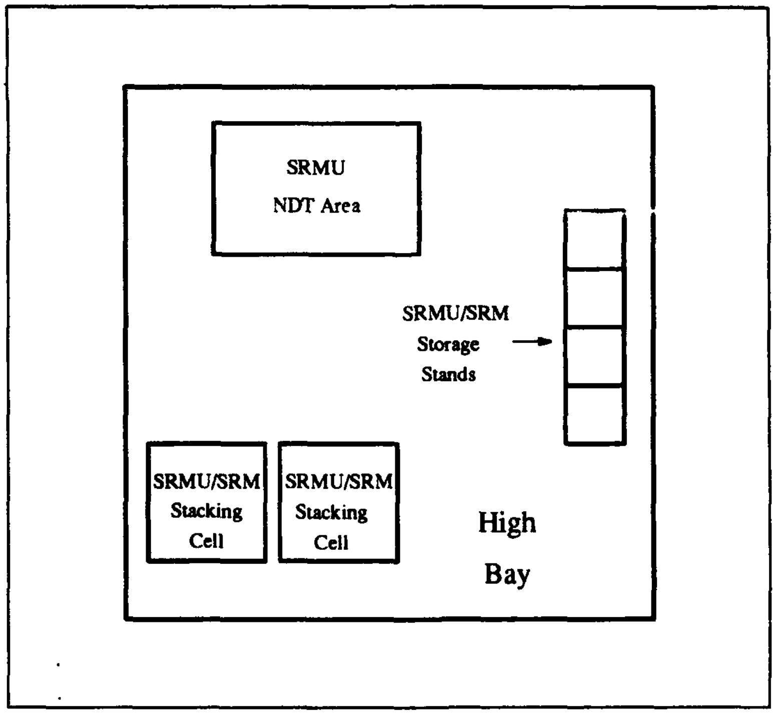

Figure 3.6. Layout of the Solid Motor Assembly and Readiness Facility (SMARF).

segments undergo non-destructive testing in the SMARF, not the SRM processing area. Once non-destructive testing is complete, three segments are stacked in the SRMU/SRM stacking cell to complete one SRMU. The SMARF has two tacking cells that can stack SRMUs and SRMs. The SMAB does not have the capability to stack SRMUs. The SMARF has four SRMU/SRM storage stands to give flexibility to this phase of launch processing. The core vehicle arrives at the SMARF after its final assembly in the VIB is complete. Upon arrival at the SMARF, the core vehicle is mated to the SRMUs or SRMs.

3.1.2.4 Launch Pad Activities. After the booster vehicle is on the launch pad, the pad processing activities begin. For SRMs that are processed through the SMAB, the final two segments and the SRM forward closures are transported separately to the launch pad. These segments are stacked at the launch pad to complete the seven-segment SRMs. However, for SRMs that process through the SMARF instead of the SMAB, the boosters are completely stacked in the SMARF and there is no requirement for this launch pad activity. Once the SRMs are complete, integrated CV/SRM testing is performed. These tests are performed with the Rocket Motor Test Set (RMTS). After these tests, the CV/SRM or CV/SRMU mated configuration on the pad is called the Booster Vehicle (BV).

At this time, the vehicle is mated with its upper stage, if there is one, for the particular mission. Upper stage mating is performed on the launch pad followed by installation of the lower payload fairing for the TIV/IUS configuration. A baseline CST is then performed.

Next, the payload is brought to the launch pad for mating onto the upper stage. Titan IV payloads are varied and require some amount of stand-alone time on the launch pad. Payload processing time can be considerable, taking up to 100 days for some payloads and dramatically lengthening the total Titan IV processing times (17). However, for this study, a standard unclassified value of 26 calendar days of

spacecraft stand-alone time on the pad is used. Payload-specific stand-alone time is classified for each of Titan IV's payloads and the 26 calendar days has been used in other Titan IV scheduling studies.

After payload mating, the forward payload fairing is installed to encapsulate the spacecraft and complete the launch vehicle build-up. This configuration of the Titan IV is known as the launch vehicle (LV). Launch vehicle integrated testing is performed as the third and final CST, called Launch CST. In many cases, an Integrated Systems Test (IST) with the spacecraft is performed in lieu of the Launch CST. After final activities are performed, including the fuel and oxidizer loading, the Titan IV is ready for launch and fulfillment of its mission to deliver a payload to orbit.

3.2 Critical Path Analysis

Network models can be used to schedule large complex projects consisting of many activities such as the launch processing required for an expendable launch vehicle. If the duration of each activity is known with certainty, then critical path analysis is used to determine the length of time required to complete the project. This analysis is also used to determine how long each activity in the project can be delayed without delaying the completion of the total project (33:398).

For a network constructed of arcs and nodes as shown in Figure 3.7, each arc represents an individual activity of a project while each node represents a milestone toward project completion. Paths are continuous flows through the network from the project start at the initial node to the project completion at the terminal mode. An example of a path in the network shown would flow from Node 1 to 3 and then to Node 5, 9, 11 and finally end on Node 12. Notice that there can be numerous paths through a network.

The activity durations along each network path can be summed to determine its path length. The network path with the longest time to complete is identified

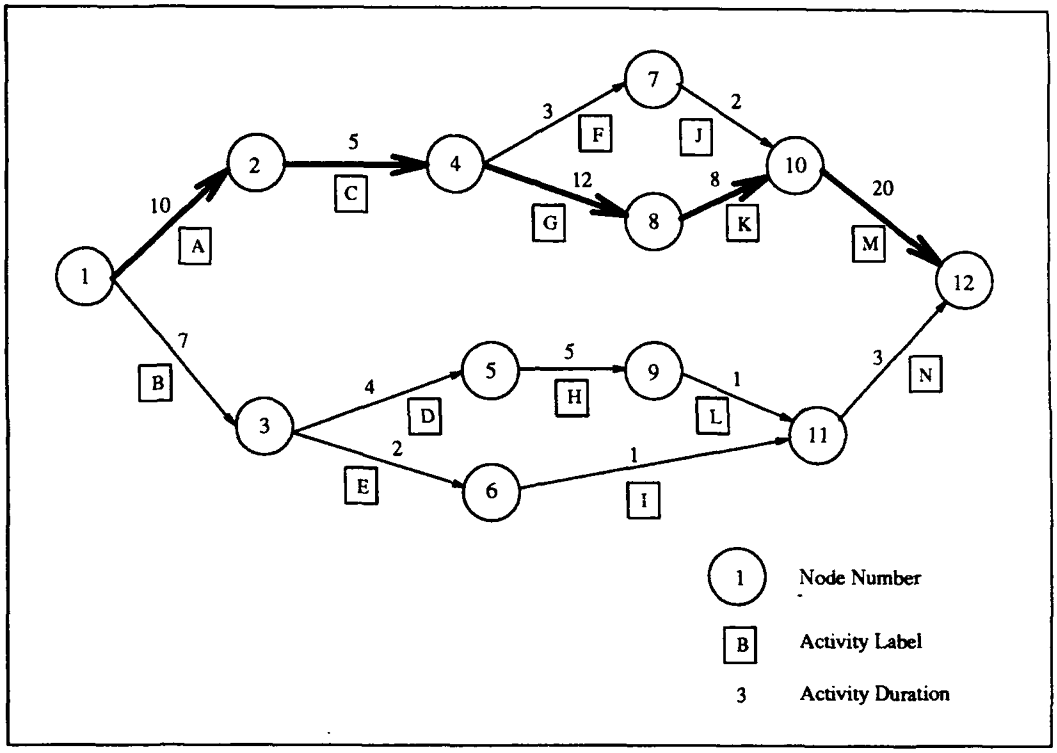

Figure 3.7. Critical Path Analysis Example.

as the "critical path." This path is critical because the completion of the entire project depends only on the time taken to complete its activities. Slack exists in the activities along the non-critical paths because the start times of these activities may be delayed by their individual "slack times" without affecting the completion time of the project. By its definition, the slack times of all activities along the critical path are zero. Thus, any delay in the start time of a critical path activity delays the completion of the entire project.

As an example of critical path analysis, consider again the network depicted in Figure 3.7. This network consists of 14 distinct activities separated by 12 nodes. The beginning of the project is designated by the initial node, Node 1, while project completion is the terminal node, Node 12. The duration of each activity is listed above each activity arc and the activity label is boxed beneath each arc. For this

example there are four separate paths through the network. The critical path analysis results are listed in Table 3.4 by path number and nodes. Path 2 ($1 \rightarrow 2 \rightarrow 4 \rightarrow 8 \rightarrow 10 \rightarrow 12$) in this example has the greatest path length and is the critical path, which is the reason for its bold depiction in Figure 3.7.

Table 3.4. Critical Path Analysis Results.

Path	Path Route	Path Length
1	$1 \rightarrow 2 \rightarrow 4 \rightarrow 7 \rightarrow 10 \rightarrow 12$	40
2	$1 \rightarrow 2 \rightarrow 4 \rightarrow 8 \rightarrow 10 \rightarrow 12$	55
3	$1 \rightarrow 3 \rightarrow 5 \rightarrow 9 \rightarrow 11 \rightarrow 12$	20
4	$1 \rightarrow 3 \rightarrow 6 \rightarrow 11 \rightarrow 12$	13

3.2.1 Near-Critical Paths. The critical path is computed by adding the successive arc times of its activities. Other paths which have lengths near the critical length are called near-critical paths. In actuality, the completion times of the network activities are not deterministic but vary in a probabilistic manner. As an example, an activity's specified duration of 12 time units may vary from 10 to 15 time units. Thus, a near-critical path may become the critical path due to the underlying random nature of the activity times. An awareness of this situation is necessary when performing a critical path analysis.

3.3 Top-Down Analysis

Top-Down analysis is an approach to decision making designed to provide the necessary understanding of the trade-offs and impacts involved in making a decision (27:1). The formalized method of the Top-Down approach was developed by STR Corporation of Reston, Virginia.

The disciplined application of the Top-Down approach takes the decision-maker out of the role of a passive executive to whom "answers" are fed from some "black

box." It places him into the role of an active executive able to apply his judgement and expertise in arriving at a decision (27:2). To fully demonstrate the value of this methodology, a description of the traditional "bottoms-up" approach is beneficial.

3.3.1 Traditional "Bottoms-Up" Approach. The traditional modeling approach begins by carefully identifying all of the variables or factors that apply to the problem. Each of the variables is explained in great detail, and relationships are established among them. These relationships are then combined at increasingly higher levels of aggregation until eventually all are linked to form some reasonably complete model of "reality." The hope is that this model of reality will support the decision to be made so that the analysis will yield "answers" (27:1).

There are several problems inherent in the traditional approach. First and foremost, the resulting model contains too much detail. Unnecessary detail not only introduces factors irrelevant to the decision, but also adds to the complexity and size of the model. The detail and complexity of the model limits the breadth of the system that can be treated. As a result, the model and the resulting analyses often omit significant components of the system that impact strongly on the decision. Data development is difficult and time consuming, and the values are often not known or cannot be computed. Traditional models contain numerous assumptions regarding factors not modeled. While assumptions are present in all modeling, the size and complexity of traditional models often bury the assumptions so deeply that they are easily hidden and forgotten. The output is usually voluminous numerical information to eight or more decimal places, even when the input data may have been accurate only to one or two decimal places (28:3).

3.3.2 Top-Down Approach. In contrast, the Top-Down approach to problem solving is designed not to give "answers" but to give the necessary understanding of the trade-offs and impacts of the decision. It also provides the decision-maker with a model to assist in visualizing relationships among alternative courses of action,

assumptions, and unknown factors. Structuring the problem around the decision to be made is the foundation of the Top-Down approach (27:1). Ten general principles helpful in conducting a Top-Down analysis are (27:1–2):

1. Begin with the particular decision to be made. Examine how the problem fits into larger decisions.
2. Throughout the analysis, question everything – – even the "well-known truths."
3. Simplify the problem as much as possible.
4. Begin at the top and work down. Develop relationships among the major variables first, and then develop the relationships among the subsidiary variables that impact upon the major variables.
5. The deeper the structure is, the less transparency it has. Keep the level of subsidiary variables examined shallow.
6. Assure consistency of assumptions.
7. Combine small unknowns or uncertainties into a few macro variables.
8. Estimate the value of unknowns then conduct sensitivity analyses around the guess.
9. Back into the answer. A Top-Down approach permits the decision-maker to start with a proposed decision and "back into" the range of data and assumptions necessary for each alternative to be the correct one.
10. Present the results as curves, never as "point solutions."

These ten general principles take the decision-maker out of the role of a passive observer to whom answers are fed. They place him in the active role, applying his judgement to arrive at a decision.

3.3.3 Trade-Off Curves. A "trade-off curve" or "phase diagram" is an example of an analytic tool used with Top-Down analysis. The trade-off curve encompasses the major components of the decision, graphically illustrates these components, and permits the decision-maker to apply his judgement to the analysis. It is a "graphical computer" that portrays all of the components of the problem, permits selection of alternative assumptions, and computes the answer resulting from these assumptions.

Trade-off curves depict the inherent relationship between two variables. For example, fuel economy listed as miles per gallon (MPG) and engine size are two decision variables for anyone shopping for an automobile. The decision might be *what combinations of these two factors could be obtained in a car for a purchase price of $15,000 or less.* A trade-off curve between these two factors clearly showing the decision space is shown in Figure 3.8. The relationship between these variables

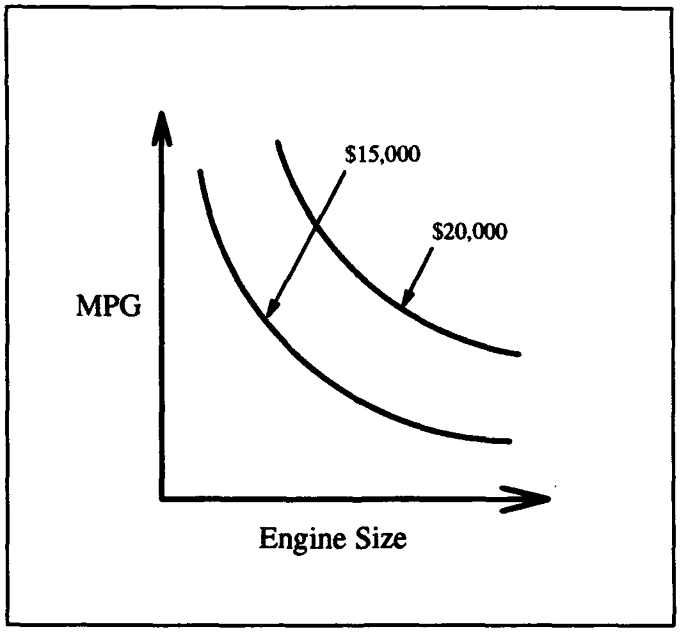

Figure 3.8. Trade-Off Curve Example of Automobile MPG versus Engine Size.

is decreasing MPG with increasing engine size. The "iso-price" curves represent combinations of the two decision variables along which the purchase price is constant.

For the decision above, any point in the decision space that lies on or below the \$15,000 price curve yields an affordable alternative. Using this type of graphical representation, the inherent trade-off between variables is shown in the context of the decision to be made.

Trade-off curves may have as few as two dimensions, or they may have multiple dimensions that share common axes. By sharing common axes, the trade-off curve links variables and permits a sequential computation of a solution to a problem. Trade-off curves are quite different from traditional models. The graphical representation allows visualization of how a change in one factor impacts on the result; or, how much a particular variable could change before the decision would change. Sensitivity analyses are easily accomplished and result in a range of outcomes instead of point solutions associated with traditional analyses (5:2–4).

3.3.4 Backing-in. Backing-in is one of the most important reasons why the Top-Down approach is so much more efficient than the traditional approach in modeling. Backing-in starts with a proposed decision and "backs into" the range of data and assumptions necessary for each alternative to be the correct one (26:6). For this analysis, backing-in starts with the question of how to make the Titan IV a responsive launch system and backs-into the range of data where Titan is responsive, exposing the assumptions in the process.

Backing-in has been successfully applied to decisions relating to the selection of alternative technologies, to federal regulations on ingredient labeling, and to construction of additional plant capacity. In each case the Top-Down approach of backing-in has proven superior to the traditional bottoms-up approach to analysis in terms of lower cost, less time, more focused information, and considerably deeper insights (26:8).

Whenever a decision depends more on what the decision-maker believes about uncertainties and unknowns than on hard, known facts, which is usually the case

for a difficult decision, backing-in clearly communicates the following message to the decision-maker: "If you believe 'a, b, and c' about the unknowns, then the right decision is 'X'." Backing-in also provides the message "If you believe that 'X' is the right decision, then you must believe 'a, b, and c' about the unknowns" (26:8).

3.3.5 Benefits of Top-Down Analysis. The Top-Down approach with the backing-in strategy leads the decision-maker to evaluate the comprehensive consequences of his beliefs and provides a framework to evaluate them against the decision to be made. According to Scott Meyer of STR Corporation:

> Top-Down with backing-in is *not* the right approach for the decision-maker who has already *made* a decision and wants an analysis to justify it. The Top-Down approach *is* the right approach for the decision-maker who wants insights into the decision and an opportunity to apply his judgement to making it in a structured and disciplined way. (26:8)

The following five points summarize the benefits of the Top-Down approach (28:4):

1. Top-Down incorporates a global perspective and abandons minute detail in favor of comprehensiveness.
2. Top-Down identifies those elements that have the greatest impact and focuses the decision on them.
3. Assumptions are numerous and easily identified to facilitate the analysis of different scenarios.
4. Data problems are minimized.
5. Top-Down enables the decision-maker to move from decision to assumptions.

Top-Down analysis provides the answer to the question frequently asked by top management: "What assumptions would have to be made in order for decision X to be the right one?"

IV. A Top-Down Model of Titan IV Launch Operations

The first step of the Top-Down analysis approach is to determine the particular decision to be made. In this case, the question to be answered is:

> "Can the Titan IV launch vehicle provide the U.S. with a *responsive* heavy-lift launch capability?"

4.1 Top-Down Model

Using the Top-Down technique, the major factors of launch processing for Titan IV at CCAFS are:

- Assembly activities
- Testing activities
- Trans-shipment activities

As stated in Chapter II, assembly activities include the mechanical and electrical integration tasks performed in preparing the Titan IV launch vehicle and its payload for launch. Testing activities are those performed to ensure proper functionality and safety of the launch system. As discussed previously, testing tasks are performed throughout the Titan IV launch processing sequence. An example of a testing task is the Combined Systems Test (CST) that occurs on three separate occasions during Titan IV launch processing. Trans-shipment activities are required to transport the launch vehicle hardware between facilities of the ITL Area. An example is the movement of the core vehicle on its transporter from the VIB to the SMAB.

The total duration of Titan IV launch processing is a function of the time required for these three activities - - assembly, testing, and trans-shipment - - along

the critical path. The fundamental Top-Down Titan IV launch processing model is shown in Figure 4.1. This apparently simple model presents the factors which

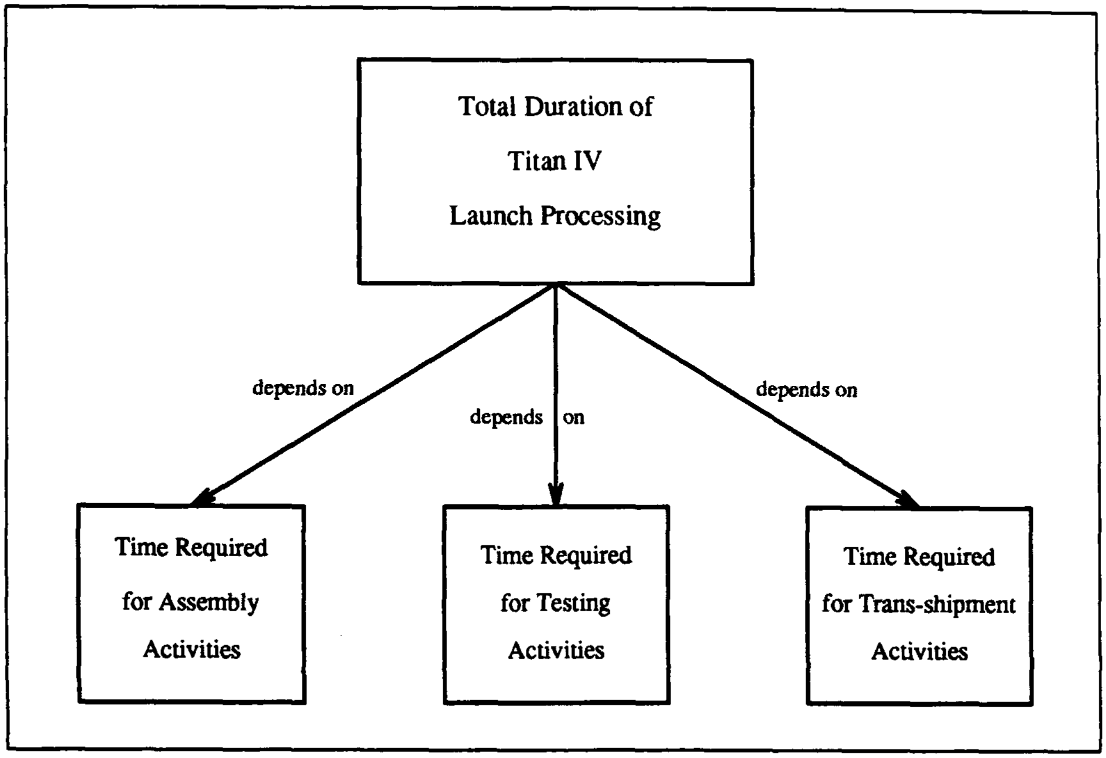

Figure 4.1. Top-Down Titan IV Launch Processing Model.

determine the total processing time. To achieve a responsive launch capability by reducing launch processing time, the time required to accomplish assembly, testing, and trans-shipment activities must be addressed.

4.2 Resulting Decision Trade-Offs

One of the products of a Top-Down analysis is a set of parametric, or trade-off, curves that depict the effect of various levels of certain decision variables. These trade-off curves relieve the analysis of the burden of assuming particular values for the decision variables. Rather than providing a single point solution, the trade-off curves portray a range of solutions corresponding to various levels of the decision

variables. The decision-maker is then able to apply his expertise by selecting the values of the decision variables he considers most reasonable and examining the solution to the precise problem he is interested in. Decision variables for Titan IV launch processing include:

- The *number of shifts per day* to schedule the launch processing crews.
- The *degree of improvement* to make in *assembly* activities.
- The *degree of improvement* to make in *testing* activities.
- The *degree of processing* to complete before a launch call is received.

The influence of these decision variables on assembly, testing, and trans-shipment times can be addressed in the form of trade-off curves. These factors for Titan IV launch processing are graphically shown in Chapter V in a series of such curves. The basis of these graphs is launch processing data collected and derived as described in the following section.

4.3 Data Description

Information for the research consists of a top-level critical path used by Martin Marietta planners and also a Martin Marietta work schedule for generic Titan IV launch processing.

4.3.1 Critical Path of Titan IV Launch Processing. Danny C. Wyatt, a Titan IV Payload Integration Engineer for Martin Marietta, supplied the top-level critical path and the associated activity durations for Titan IV launch processing for both the TIV/Centaur and the TIV/IUS configuration. This information is displayed in Table 4.1. The activity durations shown in Table 4.1 are used for planning purposes by the Titan IV Program Control branch of Martin Marietta at CCAFS, a planning and scheduling office dedicated to Titan missions. Activity durations in this table are given in "calendar days" as opposed to "work days." The number of "calendar days"

Table 4.1. Top-Level Critical Path of Titan IV Launch Processing (35).

Activity	**TIV/Centaur**	**TIV/IUS**
Core Vehicle Processing in VIB Low Bay	30 days	30 days
Core Vehicle Processing in VIB Cell	77 days	77 days
CV Mate with SRMs or SRMUs	7 days	7 days
Upper Stage Mate and Processing on Pad	52 days	32 days
Satellite Mate and Processing on Pad	26 days	26 days
Payload Fairing Attachment	8 days	11 days
Final Processing to Launch	10 days	10 days
Total Processing Time for Titan IV	210 days	193 days

includes the number of work days plus all weekends and holidays that occur during the launch processing of a particular vehicle. The 10 days of "Final Processing to Launch" in Table 4.1 is 10 calendar *or* work days because the launch processing flow is not interrupted for weekends or holidays during this phase. There are no launch processing paths for Titan IV that are close in length to this top-level critical path. Therefore, consideration of near-critical paths is not necessary for this analysis.

The other information used in this research, the work schedule, was produced by the Titan IV Launch Operations Planning branch of Martin Marietta on 15 May 1992 at Cape Canaveral AFS (29). This work schedule covers the processing flow for the launch system configuration of a generic Titan IV with Solid Rocket Motors (SRMs) and a Centaur upper stage. This information is shown in Tables C.2 and C.4 located in Appendix C. No information for the other Titan IV configurations, such as Titan IV with SRMs and an Inertial Upper Stage, was used in the analysis.

Martin Marietta's work schedule provides data on the activities of transporter preparation, VIB work, and launch pad tasks. The schedule divides activities into shifts required per task. The "number of shifts" is the unit of measure used in the trade-off analysis of this thesis where one shift equals eight hours. The number

of shifts implemented per day by Martin Marietta varies for different activities of launch processing. For this analysis, it is reasonable to assume Martin Marietta can vary the average shift "intensity" from one to three shifts per day.

According to Wyatt, the critical path corresponding to the work schedule is not produced by Martin Marietta at the schedule's level of detail. Because the critical path is not specified for the work schedule, the specific activities on the critical path were inferred by comparing the detailed work schedule with the top-level critical path. The length of the inferred critical path resulting from this comparison corresponds closely to the length of the top-level critical path, as demonstrated at the end of this chapter. The activities from the work schedule determined to be on the critical path are shown in Tables C.2, C.3, and C.4 in Appendix C.

Activities from the schedule were assigned to the three categories of the Top-Down model – – assembly, testing, and trans-shipment. Table 4.2 shows a summary of the data derived from the work schedule for the entire processing of a Titan IV launch vehicle, while Table 4.3 shows a summary of the derived data for the inferred critical path. Wyatt indicates that the duration of the inferred critical path is

Table 4.2. Titan IV Total Processing Summary Data.

Location	**Assembly Activities**	**Testing Activities**	**Trans-shipment Activities**	Total
VIB	310 shifts	179 shifts	6 shifts	495 shifts
SMAB	5 shifts	0 shifts	1 shift	6 shifts
Launch Pad	313 shifts	591 shifts	0 shifts	904 shifts
Total	628 shifts	770 shifts	7 shifts	1405 shifts

reasonable for analysis purposes (38). As seen in both of these tables, the shifts required for trans-shipment are negligible in comparison to assembly and testing shifts. Because trans-shipment activities have virtually no influence on the duration of launch processing, they are not discussed further. The work schedule provides the

Table 4.3. Titan IV Critical Path Processing Summary Data.

Location	Assembly Activities	Testing Activities	Trans-shipment Activities	Total
VIB	63 shifts	50 shifts	2 shifts	115 shifts
SMAB	5 shifts	0 shifts	1 shift	6 shifts
Launch Pad	83 shifts	51 shifts	0 shifts	134 shifts
Total	151 shifts	101 shifts	3 shifts	255 shifts

total number of work days for activities at the VIB and the launch pad. A summary of this information is displayed in Table 4.4.

Table 4.4. Critical Path Processing Summary Data in Work Days.

Activities	Work Days
VIB Activities	63
SMAB Activities	6
Launch Pad Activities	70
Total	139

As a check to the inferred critical path data shown in Table 4.3, the critical path in shifts can be derived from the top-level critical path obtained from Martin Marietta. The 210 calendar days of total processing time for the Titan IV configuration shown in Table 4.1 converts to 153 work days, not including holidays, due to the final 10 days being either work or calendar days. Estimating that six of the 12 yearly Martin Marietta holidays occur during the launch processing for a particular vehicle, the resulting total processing time along the critical path for this Titan configuration is 147 work days. The 147 work days in this case is reasonably close to the inferred work schedule result of 139 work days.

V. A Top-Down Analysis of Titan IV Launch Operations

The Top-Down analysis of Titan IV launch processing is presented in this chapter as a series of trade-off curves. These curves depict how the factors under study influence the Titan IV launch processing system and present a way to address the feasibility of Titan IV responsive launch operations.

5.1 Existing Launch Processing

The existing sequence of launch processing activities for Titan IV was explained in Chapter III. Current procedures call for the start of the processing flow to begin upon the notification of a launch order. As such, no launch processing activities are conducted prior to a launch call.

5.1.1 Shift "Intensity" per Day. As seen previously in Table 4.3 of Chapter IV, current Titan IV launch processing requires 255 shifts along the critical path. Subtracting the three shifts of trans-shipment activities along the critical path, determined to be negligible for this analysis, yields 252 shifts of total launch processing. These shifts are spread over 139 work days resulting in an average shift "intensity" of 1.8 shifts per day. It is important to note that 139 days of total processing exceeds what could reasonably be considered as responsive.

An inverse relationship exists between the total duration of launch processing and the number of shifts per day implemented by Martin Marietta for the activities on the critical path. As the average shift intensity increases, the total length of Titan IV launch processing decreases. Figure 5.1 illustrates this relationship between the total duration of launch processing and the number of shifts worked per day. The algebraic relationship of Figure 5.1 is

$$\text{Total Processing Duration in Work Days} = \frac{252 \text{ Total Shifts Required}}{\text{Shifts per Day}}.$$

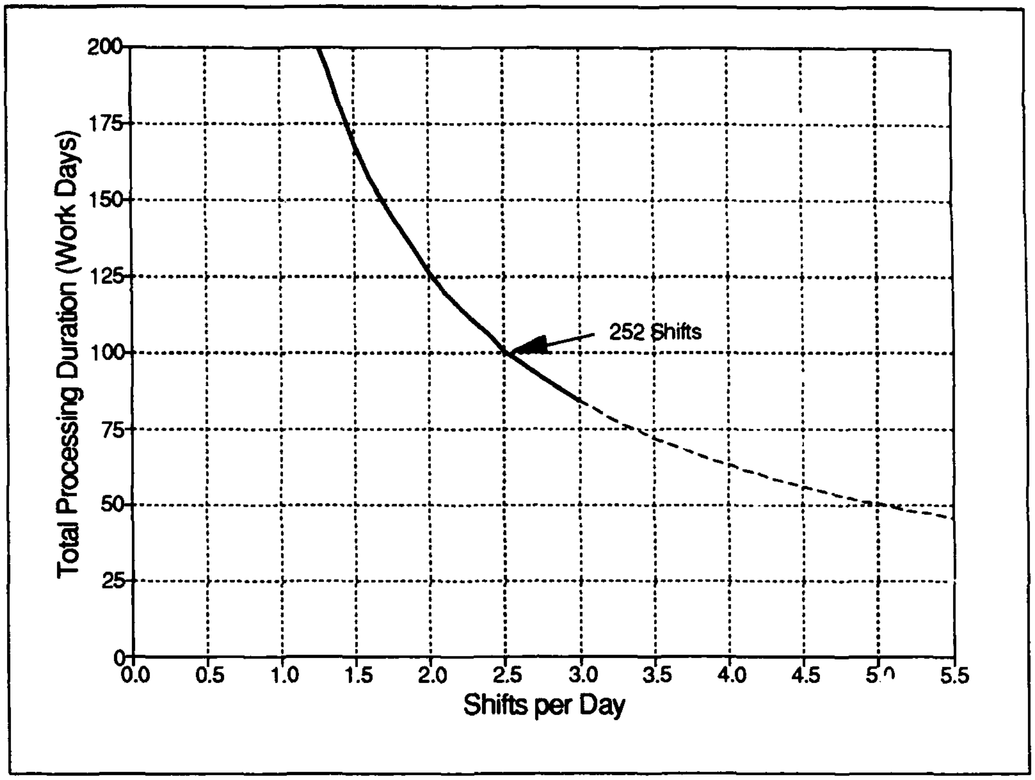

Figure 5.1. Total Duration of Launch Processing versus Shifts Worked per Day.

Notice the upper and lower bounds on the total duration depicted in Figure 5.1. The upper bound of total duration, or worst-case scenario, would result from a shift intensity of one shift per day. At one shift per day, the total launch processing duration would be 252 work days. Similarly, the lower bound, or best-case scenario, corresponds to a shift intensity of three shifts per day. The total duration of the project at this rate is 85 work days. Note that even with a shift intensity of three shifts per day, the total duration still exceeds the responsive launch definition of 60 days.

To meet the 60-day requirement under the current operations of 252 total shifts, 4.2 shifts per day are necessary. The curve of Figure 5.1 is dashed in the region past three shifts per day to indicate that extrapolation is required beyond this value. To

exceed three shifts per day requires the speculation of performing tasks in parallel with increased manning per shift. The fact that the intricacies of exceeding three shifts per day are ignored in Figure 5.1 is indicated by the dashed portion of curve.

5.1.2 Activity Efficiency Improvement. In this section, the focus is changed from shift intensity to activity efficiency by observing the effects of improvement to the assembly and testing tasks of launch processing. Figure 5.2 shows the trade-off analysis for improving the assembly activities. This curve demonstrates the rela-

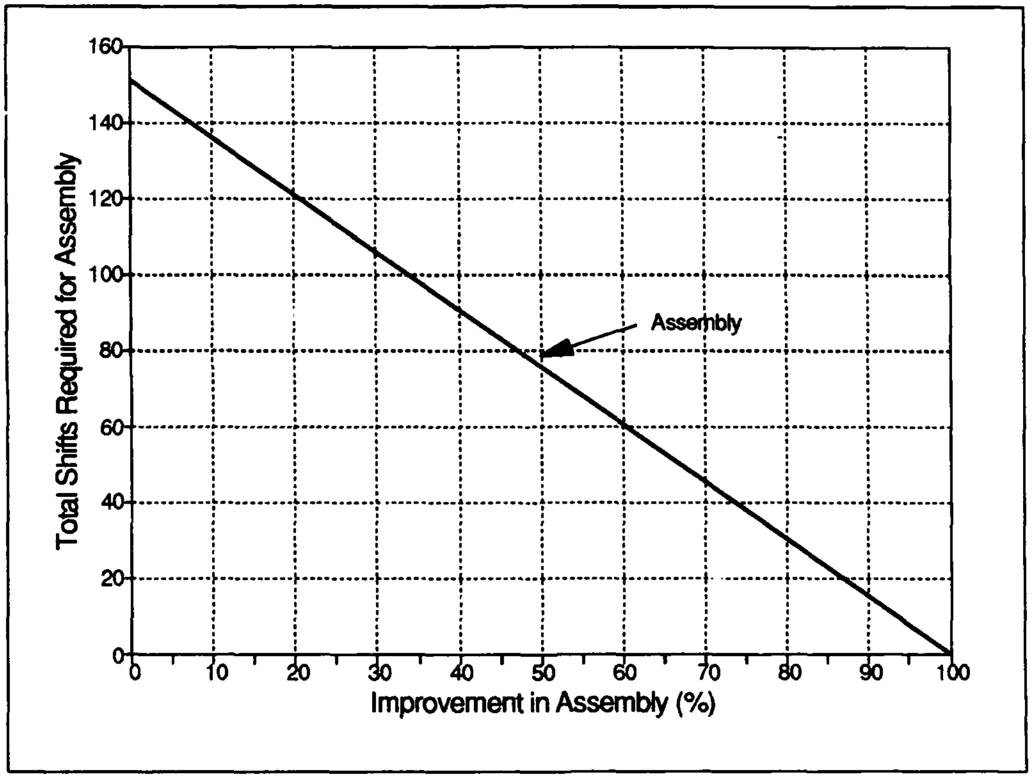

Figure 5.2. Shifts Required for Assembly versus Assembly Improvement.

tionship between the total number of shifts required for assembly activities on the critical path versus the percentage of improvements to these activities. The algebraic

relationship of Figure 5.2 is

$$\text{Total Assembly Shifts Required} = (151 \text{ Assembly Shifts})\left(1 - \frac{\%\ \text{Improvement}}{100}\right).$$

The improvements may be new assembly procedures requiring a shorter amount of time to complete, increased manpower per shift, or new hardware requiring fewer hours of assembly. Top-Down analysis does not necessarily indicate how these improvements could be implemented; it simply portrays their effect. If deemed beneficial, those individuals with the appropriate knowledge, intuition, and authority could begin to enact them. For example, improving the assembly functions by 20% reduces the number of total shifts required for assembly on the critical path to approximately 121. It's the decision-maker's role to decide if the benefits of reducing the number of assembly shifts on the critical path by 30 shifts is worth the cost associated with improving efficiency by 20%. Note that the scenario of no improvement yields the present duration of assembly activities on the critical path of 151 shifts.

Figure 5.3 demonstrates the trade-off analysis for efficiency improvements to testing activities. This curve presents the relationship between the total number of shifts required for testing activities on the critical path versus the percentage of improvement that can be made in these activities. The algebraic relationship of Figure 5.3 is

$$\text{Total Testing Shifts Required} = (101 \text{ Testing Shifts})\left(1 - \frac{\%\ \text{Improvement}}{100}\right).$$

Using this graph, improvement in testing by 10% reduces the number of total shifts required for testing on the critical path to about 91. Assumptions are not made regarding where the improvements in these testing activities can be made. Possible improvements could be shorter testing procedures or new test equipment. Notice that no improvement yields the present duration of 101 shifts for testing activities along the critical path.

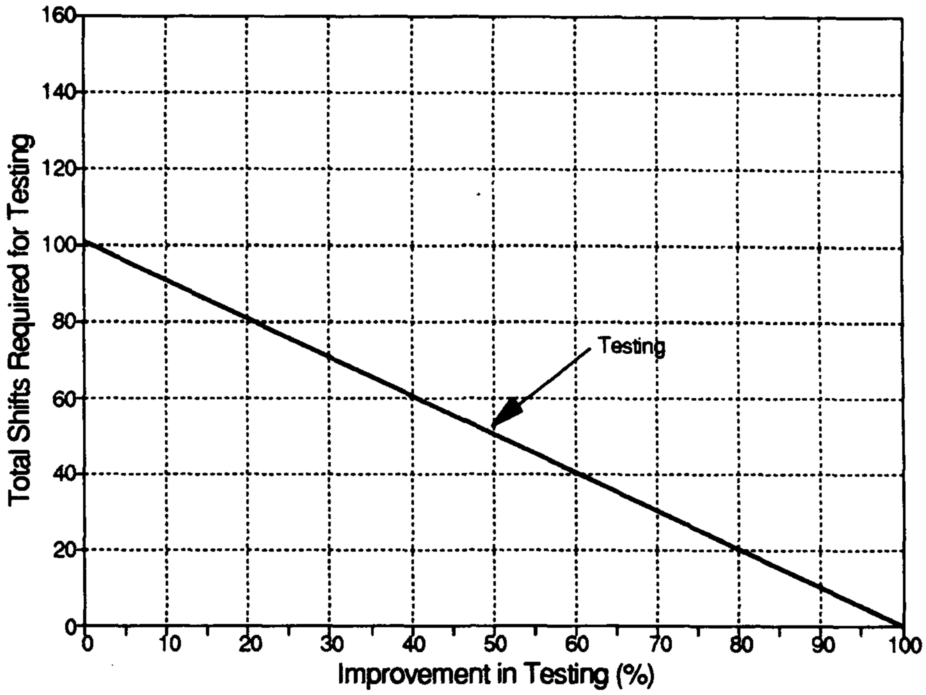

Figure 5.3. Shifts Required for Testing versus Testing Improvement.

The next trade-off curve, shown in Figure 5.4, combines Figure 5.2 and Figure 5.3 in one decision space to show the relationship between the number of shifts required along the critical path and improvement in either assembly or testing activities. This curve enables visualization of the cumulative impact of improvement in both phases.

Figure 5.5 is an "iso-shift" representation of the potential cumulative effects of improvements in either testing or assembly activities, or both. These trade-off curves are "constant shift" curves and present improvement in assembly versus improvement in testing activities for varying shift requirements on the critical path. Figure 5.5

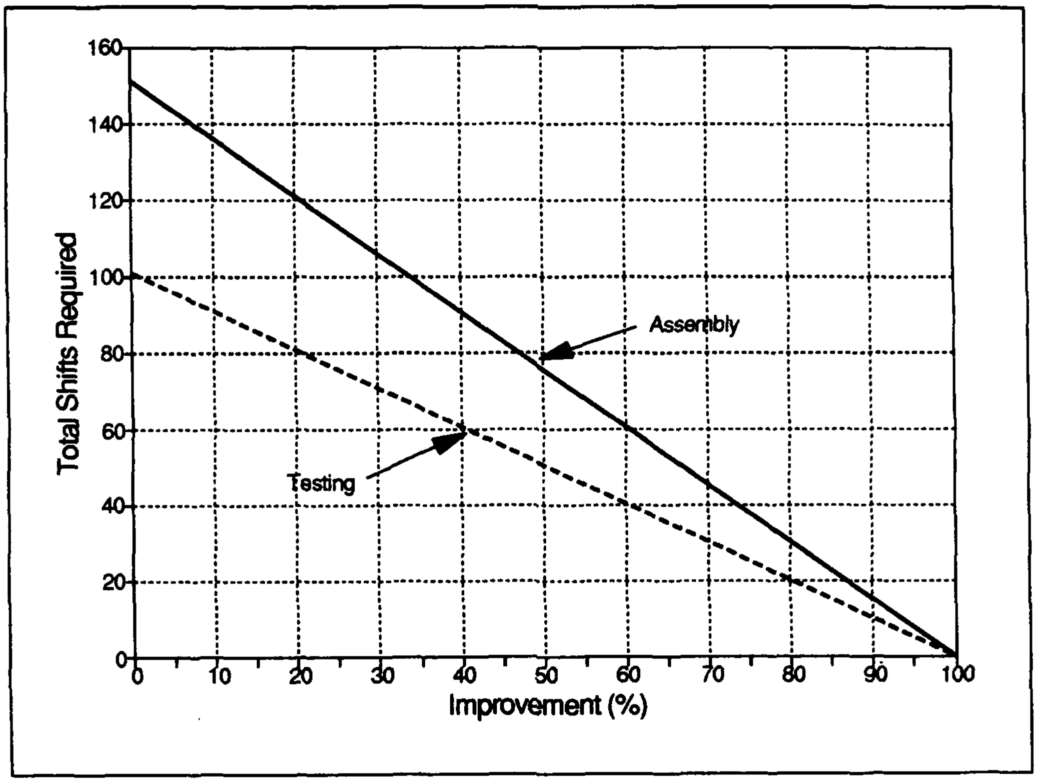

Figure 5.4. Shifts Required versus Activity Improvement.

results from the following relationship:

$$\text{Total Processing Shifts Required} = (\text{Assembly Shifts}) + (\text{Testing Shifts})$$

Solving this relationship in terms of the percentage (%) improvement in assembly activities results in

$$\%\ \text{Assembly Improvement} =$$

$$\left(\frac{(100)(101)}{151}\right)\left(1 - \frac{\%\ \text{Testing Improvement}}{100}\right) -$$

$$(100)\left(\frac{\text{Total Shifts Required}}{151} - 1\right).$$

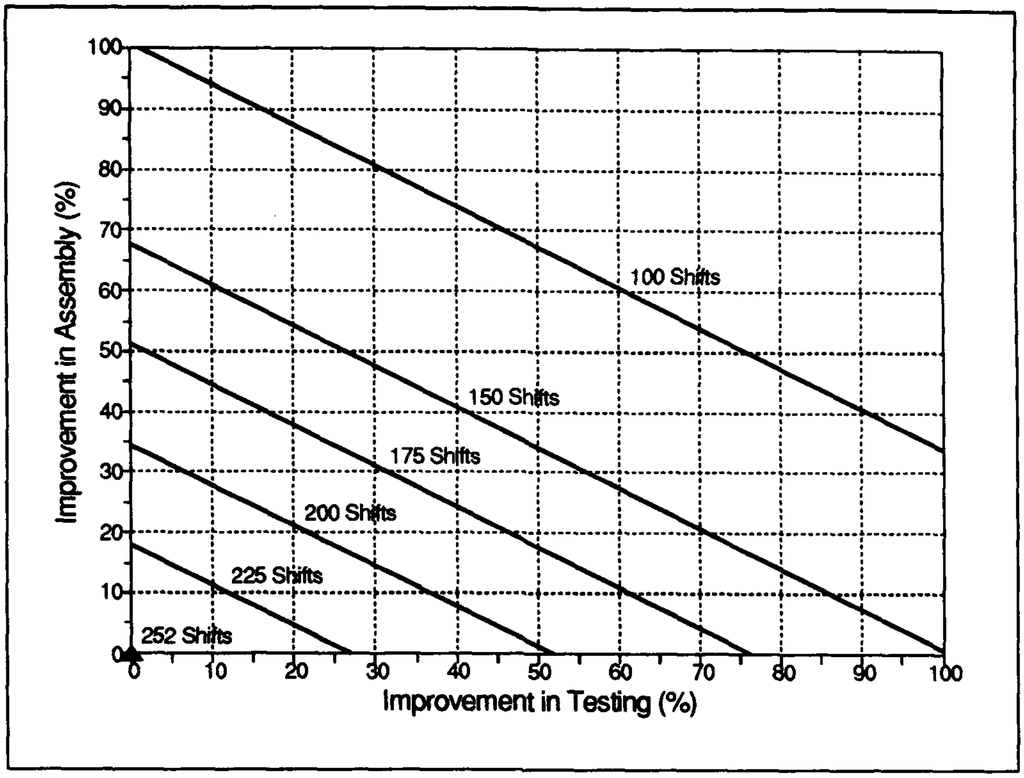

Figure 5.5. Assembly Improvement versus Testing Improvement.

As an example, a 30% improvement in testing procedures coupled with a 15% improvement in assembly activities results in 200 total shifts required for assembly and testing on the critical path. The current duration of 252 shifts for Titan IV launch processing is depicted on this curve as zero percent improvement in both assembly and testing. Notice that Figure 5.5 can be used to evaluate the overall effect of proposals for improvements to assembly and testing activities.

5.1.3 Shift "Intensity" per Day after Improvement. With the potential to reduce the number of shifts on the critical path, it is worth examining the effect of a range of shift intensities on the duration of launch processing for a number of total shift requirements. Figure 5.6 portrays the total duration of launch processing versus the number of shifts worked per day for a variety of total shift requirements.

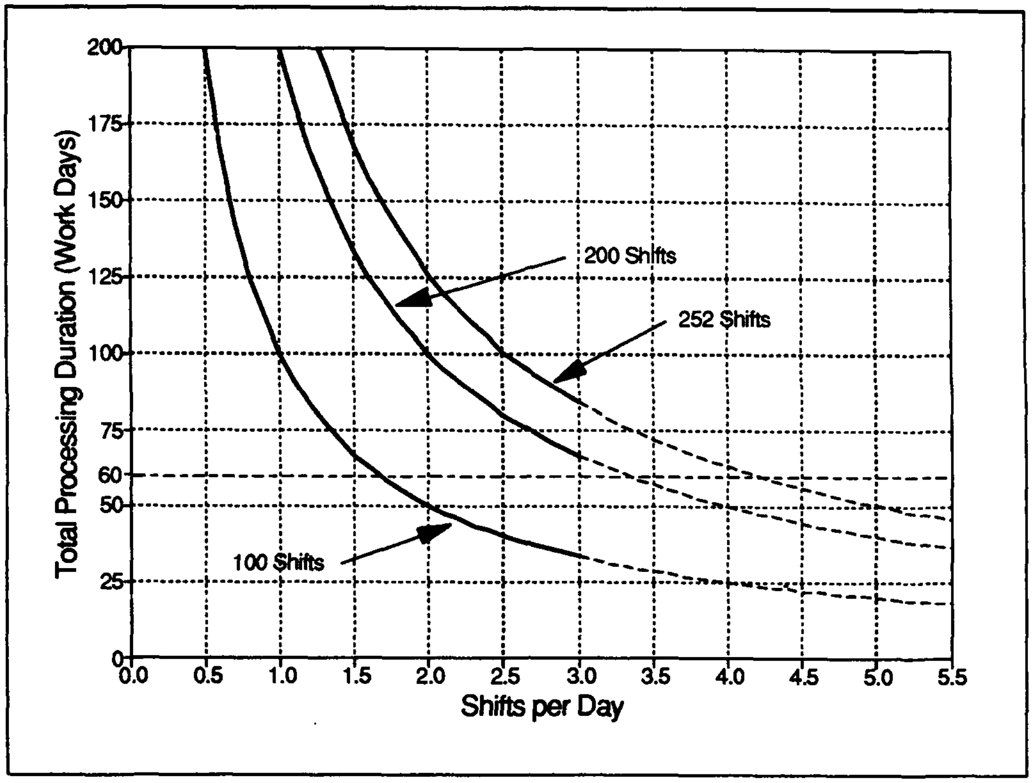

Figure 5.6. Total Duration of Launch Processing versus Shifts Worked per Day for Different Total Shifts Required After Efficiency Improvements.

The algebraic relationship of these curves is

$$\text{Total Duration in Work Days} = \frac{\text{Total Shifts Required}}{\text{Shifts per Day}}.$$

The figure shows the curves for 100, 200, and the present processing scenario of 252 total shifts required for the critical path. As an illustration, consider the previous example. Figure 5.5 reveals that a 30% improvement in testing procedures coupled with a 15% improvement in assembly activities results in 200 total critical path shifts required. Figure 5.6 yields the total duration in work days as a function of the average number of shifts per day. For 200 shifts and the current average shift intensity of 1.8 shifts per day, the total processing duration is about 111 work days.

Even with a shift intensity of three shifts per day, the launch processing cannot be accomplished in 60 days or less for a total shift requirement of 200 shifts. Notice that the curves are broken in Figure 5.6 for values greater than three shifts per day because this region is speculative as previously described. Applying the speculative region of the curve indicates that launch processing requiring 200 shifts could be completed in 60 days with a shift intensity of 3.3 shifts per day.

The decision space for Titan IV responsiveness is clearly defined in Figure 5.7. This figure shows the total launch processing shifts required as a function of the shift

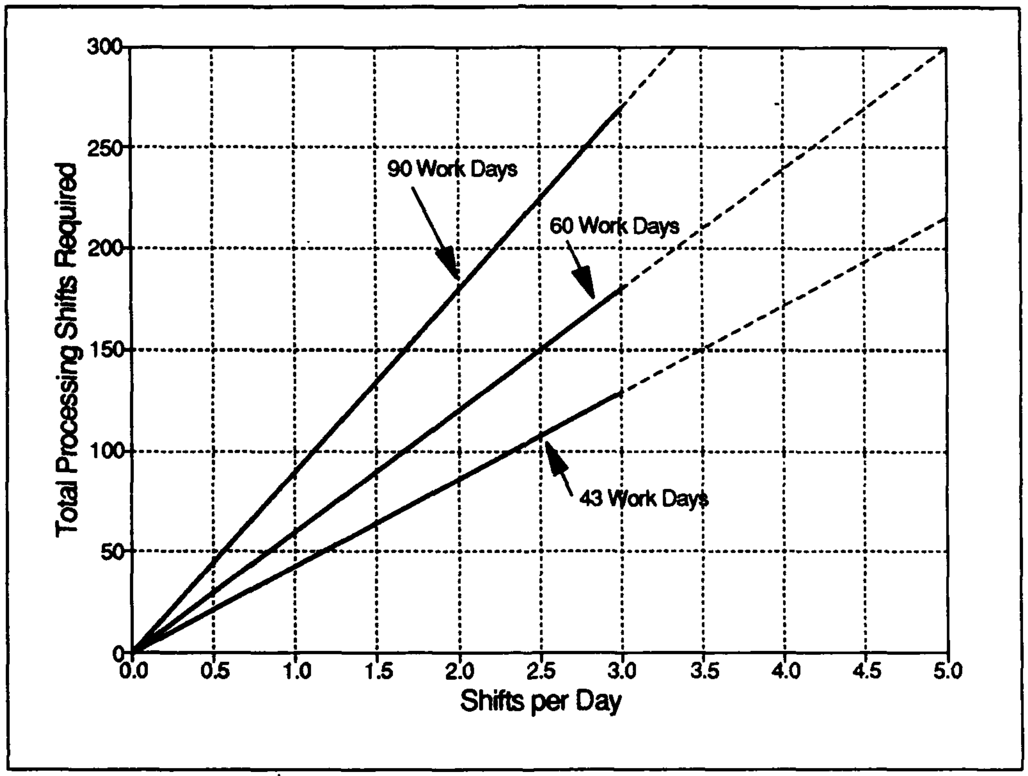

Figure 5.7. Total Shifts Required versus Shifts Worked per Day for Different Total Work Days.

intensity in "iso-work day" curves. The algebraic form of Figure 5.7 is

$$\text{Total Processing Shifts Required} = (\text{Duration in Work Days})(\text{Shifts per Day}).$$

This graph provides the complete array of decision alternatives. Combinations of total shifts and shift intensity on or below the 60 Work Days curve result in a responsive Titan IV launch capability. Combinations above this curve are non-responsive. Note that if seven-day work weeks are not implemented, then the 60-day responsive launch requirement would be 60 "calendar" days, which converts to 43 work days ignoring holidays. A curve for 43 work days is also plotted in Figure 5.7.

5.2 Modified Launch Processing Concept

Another method of attaining responsive launch for Titan IV is to modify the current practice of initiating processing upon notification of a launch order. The change involves some amount of launch processing before the "launch call" is received. This "pre-processing" could be either assembly, testing, or both. A form of this concept is advocated by General Charles Horner, Commander-in-Chief of U.S. Space Command, who stated that space systems should be built launch-ready, rather than "built on the pad" (12:30). Improvements in assembly and testing activities could also be integrated into this concept. The following trade-off curves illustrate the effect of combining the modified launch processing concept with the previously discussed efficiency improvements.

5.2.1 Pre-Processing Trade-Offs. Figure 5.8 shows the processing required after a launch call is received based on the shifts of pre-assembly and pre-testing activities performed. Figure 5.8 graphically portrays this trade-off of "reduced shifts until launch" with the amount of pre-processing implemented. Its algebraic relationship is

$$\text{Shifts Required Until Launch} = (252 \text{ Shifts}) - (\text{Pre-Processing Shifts}).$$

If pre-processing included 100 shifts of pre-assembly or pre-testing, the processing required after a launch call would be 152 shifts. Obviously, the advantages gained by

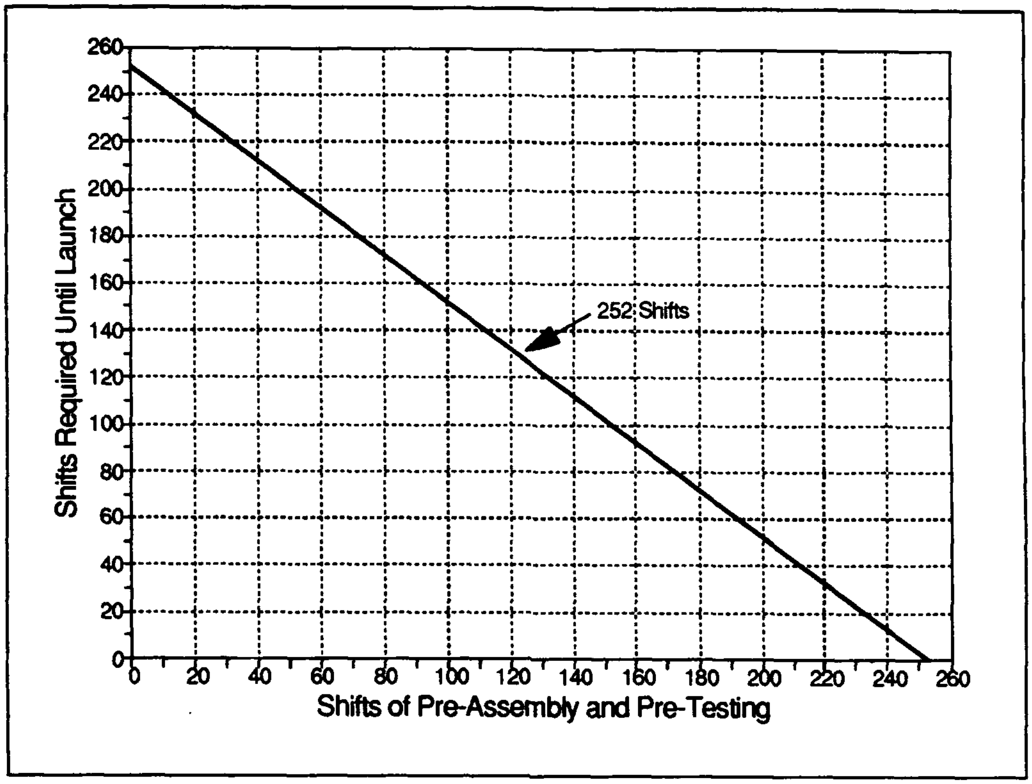

Figure 5.8. Processing Required After Launch Call versus Shifts of Pre-Assembly and Pre-Testing.

pre-processing and having equipment on alert status must be weighed against storage and security requirements of the pre-processed hardware and their associated costs.

Figure 5.9 integrates the improvement opportunities in assembly and testing activities on the critical path discussed previously with the modified concept of pre-processing. These "iso-shift" curves show the processing required after a launch call is received versus the shifts of pre-assembly and pre-testing performed. Figure 5.9's algebraic relationship is

Shifts Required Until Launch = (Total Shifts Required) − (Pre-Processing Shifts).

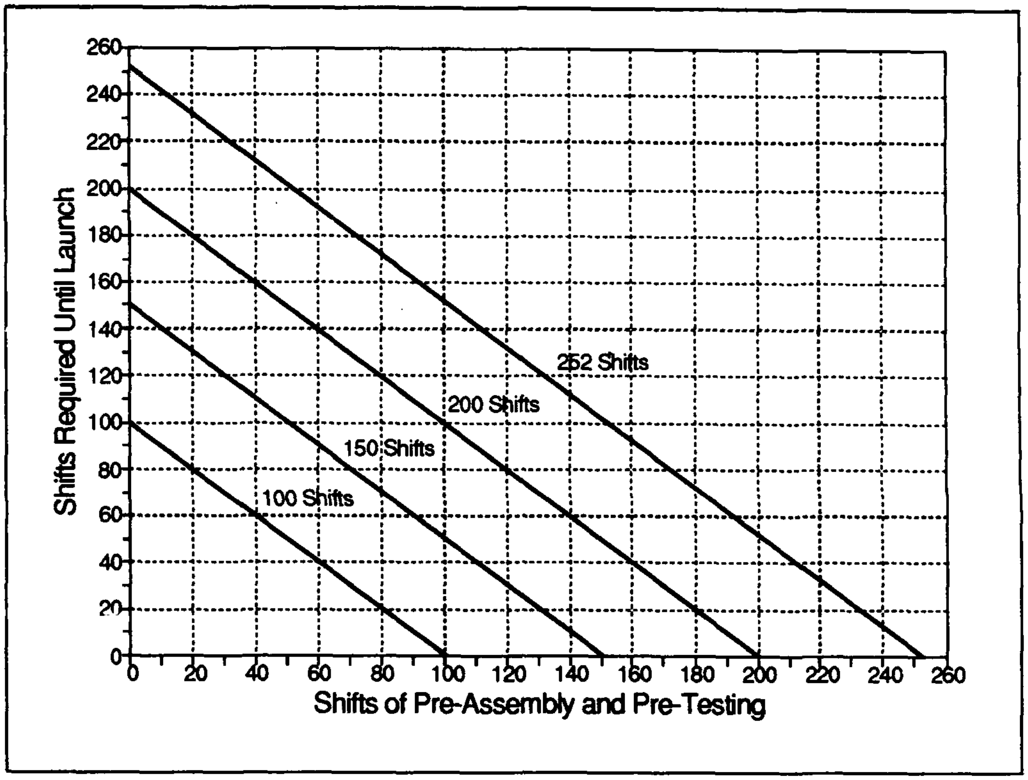

Figure 5.9. Processing Required After Launch Call versus Shifts of Pre-Assembly and Pre-Testing for Different Total Shifts Required.

The graph presents the curves for 100, 150, 200, and the present processing scenario of 252 total required critical path processing shifts. For example, if these improvements brought the total launch processing to 200 shifts on the critical path with 80 shifts of pre-processing, then only 120 additional processing shifts must be performed once a notification for launch occurs.

The number of shifts along the critical path to be accomplished after a launch call can now be plotted to determine the number of work days until launch, as shown in Figure 5.10. This graph shows the number of work days required versus the number of shifts worked per day. Its algebraic relationship is the same as Figure 5.6, which was given previously. The curves show various total shifts resulting from pre-processing, improvement to assembly and testing, or any combination of the two.

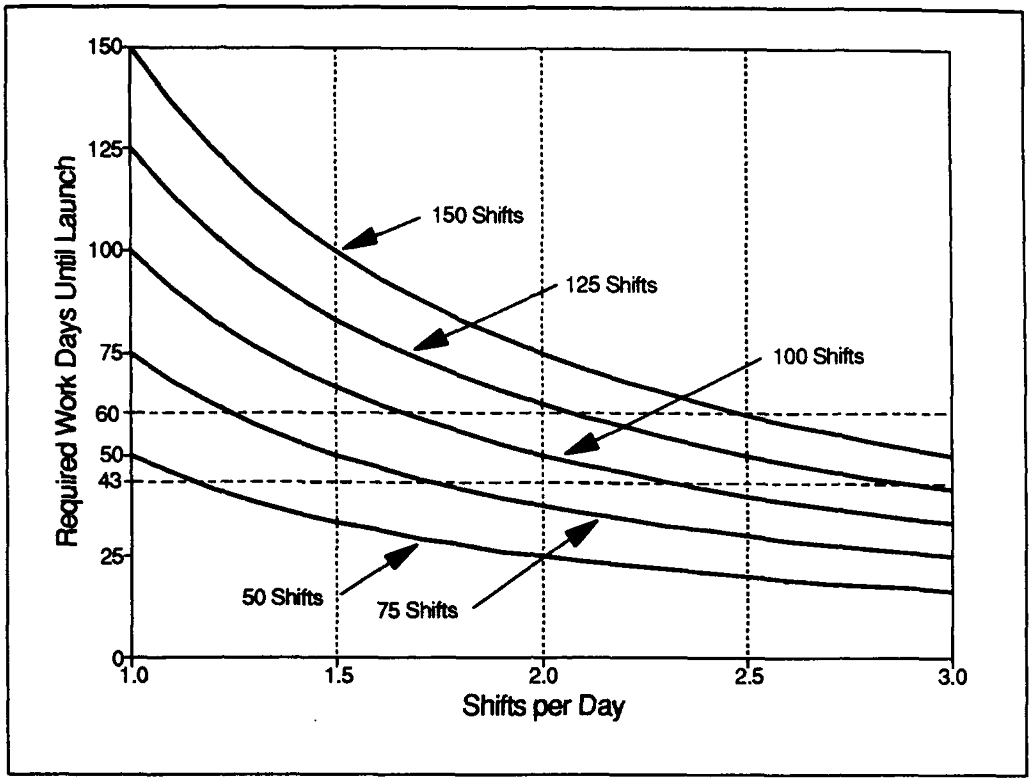

Figure 5.10. Work Days Required After Launch Call versus Shifts Worked per Day for Different Total Shifts Required.

Note that a 60-day responsive launch capability, using the current shift intensity of 1.8 shifts per day, requires a reduction in shifts conducted on the critical path after a launch call is received to roughly 105 shifts.

The decision space for Titan IV responsiveness is clearly defined in Figure 5.11. This figure shows the shifts required after a launch notification as a function of the shift intensity in "iso-work day" curves. The algebraic relationship of this graph is the same as Figure 5.7, which was given previously. Combinations of total shifts and shift intensity that fall on or below the 60 Work Days curve result in a responsive Titan IV launch capability, while those combinations above this curve are non-responsive. Note that 60 calendar days converts to 43 work days for schedules of five-day work weeks.

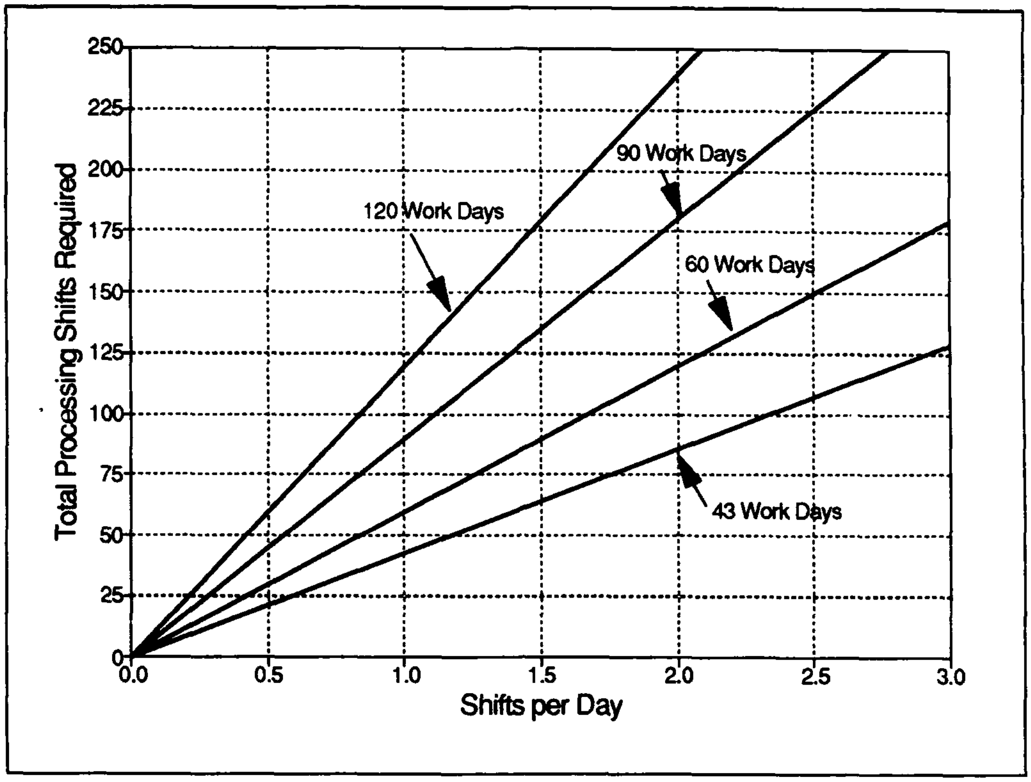

Figure 5.11. Shifts Required After Launch Call versus Shifts Worked per Day for Different Total Work Days.

5.3 Unifying Algebraic Expressions

Analysis information can be obtained directly from the algebraic relationships independent of the trade-off curves. The following equations provide a tool for point estimates, rather than the general functional dependencies portrayed in the graphs. The total processing duration in work days is

$$\text{Total Processing Duration in Work Days} = \frac{\text{Shifts Until Launch}}{\text{Shifts per Day}},$$

where the Shifts Until Launch is

$$\text{Shifts Until Launch} = \text{Assembly Shifts} + \text{Testing Shifts} - \text{Pre-Processing Shifts},$$

Assembly Shifts is

$$\text{Total Assembly Shifts Required} = (151 \text{ Assembly Shifts})\left(1 - \frac{\% \text{ Improvement}}{100}\right),$$

and Testing Shifts is

$$\text{Total Testing Shifts Required} = (101 \text{ Testing Shifts})\left(1 - \frac{\% \text{ Improvement}}{100}\right).$$

The resulting equation for Shifts Until Launch becomes

$$\text{Shifts Until Launch} =$$

$$(151)\left(1 - \frac{\% \text{ Assembly Improvement}}{100}\right) +$$

$$(101)\left(1 - \frac{\% \text{ Testing Improvement}}{100}\right) - (\text{Pre-Processing Shifts}).$$

Dividing by shifts per day yields the expression below for the total processing duration in work days.

$$\text{Total Processing Duration in Work Days} =$$

$$\frac{(151)(1 - \% \text{ Assembly Improvement} / 100)}{\text{Shifts per Day}} +$$

$$\frac{(101)(1 - \% \text{ Testing Improvement} / 100)}{\text{Shifts per Day}} - \frac{\text{Pre-Processing Shifts}}{\text{Shifts per Day}}$$

Thus, the processing duration in work days is a function of the percentage improvement in assembly, the percentage improvement in testing, the number of shifts pre-processed, and the shift intensity.

5.4 *Illustrative Examples*

The following examples provide an illustration of using the trade-off curves and equations developed in this chapter. Using Top-Down analysis, the results of various assumptions can be readily seen. Conversely, the assumptions required for desired outcomes can also be determined.

5.4.1 Example 1. Starting with assumptions and working toward the result. assume that improvements of 20% and 60% are possible in assembly and testing processes, respectively. Using Figure 5.5 or the equations developed in Section 5.3, this situation results in roughly 160 shifts for total processing along the critical path. Using the result of 160 total shifts and a standard shift intensity of 1.8 shifts per day, Figures 5.6 and 5.7 reveal a launch processing duration of about 90 work days.

5.4.2 Example 2. The implicit assumptions required by the desired result of Titan IV launch responsiveness can also be revealed through use of the trade-off curves. If launch responsiveness is defined as the requirement to launch within 43 work days of the launch call, the set of feasible combinations of "total processing shifts required" and "shifts per day" fall below the 43 work day curve in Figure 5.7. One specific combination corresponds to 2.5 shifts per day and not more than 110 shifts on the critical path. Figure 5.5 reveals those improvements in assembly and testing that might reduce the number of shifts required, while Figure 5.8 indicates the degree of pre-processing that could contribute to reducing the number of shifts on the critical path to be accomplished after a launch call. Clearly, there are a number of ways to attain a responsive launch capability, and a Top-Down analysis helps to highlight the assumptions required to obtain a particular degree of responsiveness.

VI. Conclusions and Recommendations

The official Air Force mission, *To defend the United States through control and exploitation of air and space*, emphasizes the military's reliance on space systems as a tool in both conflict and peacetime. On-orbit satellites are an integral part of this tool in supporting the requirements of end-users. They are critical to the success of combat operations, as the Persian Gulf War demonstrated. For crisis situations, sustained satellite operations are assured by one or a combination of two ways -- robustness or replacement. Robustness requires more reliable, survivable, and maneuverable satellites. Satellite replacement through responsive launch requires a space launch capability that is considerably more reactive than is available today.

The Air Force must determine which method of responsiveness best satisfies operational requirements. Air Force Space Command should advocate responsive launch capability *or* assure increased satellite robustness to compensate for unresponsive launch systems. This thesis has studied the general implications of responsive launch operations for USAF space-lift vehicles and specifically Titan IV launch responsiveness. Responsive launch requires an operational philosophy on the part of the Air Force to balance the achievement of mission success against the cost of resources to achieve that success.

Current U.S. space launch systems fail to qualify as responsive, particularly Titan IV, by taking in excess of six months to process and launch. Among the reasons for Titan IV non-responsiveness are the demand for absolute mission success, a high degree of caution in the space launch field, the recent change of responsibility for launch operations from the former Air Force Systems Command to Air Force Space Command, and inefficient testing associated with launch processing. Also contributing to Titan IV non-responsiveness is the present contract incentive structure that overwhelmingly motivates toward mission success at the expense of launch

responsiveness. If the Air Force desires responsive space launch systems, then the contracts and associated incentives must reflect this goal.

The 60-day launch responsiveness benchmark established by the MLV III proposal must be reassessed in terms of responsive space systems. Defining launch responsiveness will continue to be elusive until space system responsiveness is addressed from the perspective of the user in the field, rather than the viewpoint of the launch system. Whether the user can tolerate waiting 60 days for a replacement to be launched is a question that only the user can answer.

This research demonstrates that a Titan IV responsive launch capability may be achievable. The basis for this conclusion is the result of a Top-Down modeling approach to the problem. Top-Down analysis identifies the range of assumptions required to attain responsive launch operations. The total duration of Titan IV launch processing is primarily a function of the time required to complete assembly and testing activities on the critical path. The result of Top-Down analysis suggests two approaches to attain launch responsiveness. One approach consists of considerable improvements made in assembly and testing activities required to process a Titan IV for launch. The other is a new concept of pre-processing prior to the launch notification. Incorporating more efficient assembly and testing procedures and some degree of pre-processing appear to be the most promising alternatives. Given that the Top-Down modeling approach is useful in Titan IV analysis, a refinement of the launch processing data could produce a more detailed analysis, if necessary. Such analysis would provide a greater depth of understanding in providing responsive launch capability to the Air Force.

Appendix A. *List of Acronyms*

ACS	Attitude Control System
AFM	Air Force Manual
AFMC	Air Force Materiel Command
AFSC	Air Force Systems Command
AFSPACECOM	Air Force Space Command
AVV	Automatic Vehicle Verification
BV	Booster Vehicle
CCAFS	Cape Canaveral Air Force Station
CCET	Centaur Combined Electrical Test
CELV	Complementary Expendable Launch Vehicle
CERT	Combined Electrical Readiness Test
CDF	Combined Detonating Fuse
CST	Combined Systems Test
CT	Commercial Titan
CTF	Combined Test Force
CV	Core Vehicle
DoD	Department of Defense
DSCS	Defense Satellite Communications System
ELV	Expendable Launch Vehicle
FED	Flight Events Demonstration
FTS	Flight Termination System

GEO	Geosynchronous Orbit
GOAS	Guidance Optical Alignment System
HAR	Hardware Acceptance Review
HTPB	Hydroxy Terminated Polybutadiene
ICBM	Intercontinental Ballistic Missile
IGS	Inertial Guidance System
IST	Integrated Systems Test
ITL	Integrate Transfer Launch
IUS	Inertial Upper Stage
IVT	Integrated Vehicle Testing
KSC	Kennedy Space Center
LCC	Launch Control Complex
LEO	Low Earth Orbit
L/L	Low Level
LRE	Liquid Rocket Engine
MIS	Motor Inert Storage
MLV	Medium Launch Vehicle
MST	Mobile Service Tower
NASA	National Aeronautics and Space Administration
NDT	Non-Destructive Testing
$\mathbf{N_2H_4}$	Anhydrous Hydrazine
$\mathbf{N_2O_4}$	Nitrogen Tetroxide
NUS	No Upper Stage
ORD	Operational Requirements Document

PACE	Programmable Aerospace Control Equipment
PAGE	Programmable Aerospace Ground Equipment
PBAN	Polybutadiene Acrylonitrile Acrylic Acid
PLF	Payload Fairing
R&D	Research and Development
RIS	Receive Inspect Store
RMTS	Rocket Motor Test Set
R/W	Raceway
SAS	Segment Arrival Storage
SC	Spacecraft
SCU	Signal Conditioning Unit
SHF	Super High Frequency
SLAG	Space Launch Advisory Group
SLC	Space Launch Complex
SMAB	Solid Motor Assembly Building
SMARF	Solid Motor Assembly and Readiness Facility
SORD	System Operational Requirements Document
SPIF	Shuttle Payload Integration Facility
SRM	Solid Rocket Motor
SRMU	Solid Rocket Motor Upgrade
SRS	Segment Ready Storage
STS	Space Transportation System
SV	Space Vehicle or Satellite Vehicle
TCD	Terminal Countdown Demonstration

T&FS	Tracking and Flight Safety
TIV	Titan IV
TPA	Titan Payload Assembly
TPA	Turbo Pump Assembly
UES	Universal Environmental Shelter
U.S.	United States
USAF	United States Air Force
UT	Umbilical Tower
VAFB	Vandenberg Air Force Base
VIB	Vertical Integration Building
VMTS	Vehicle Monitor Test Set

Appendix B. *Additional Titan IV Information*

This appendix contains additional information concerning the Titan IV space launch vehicle. The information is presented in the form of tables and figures.

- General specifications of the Titan IV expendable launch vehicle are summarized in Table B.1.
- Figure B.1 shows the Titan IV/SRMU configuration.
- Titan IV's payload capability with different combinations of solid rocket motors and upper stages is summarized in Table B.2.
- Historical information concerning the five Titan IV launches to date is summarized in Table B.3.
- Definitions of the identifying numbers assigned to each Titan IV launch vehicle configuration are included in Table B.4.
- Specifications for Titan IV payload fairings are shown in Table B.5.
- Figure B.2 shows a Titan IV typical flight sequence.
- Table B.6 lists the event times and altitudes associated with each of the sample mission sequence events shown in Figure B.2.

Table B.1. Titan IV General Information (20:267–268).

Parameter	
System Height	Up to 204 ft
Gross Mass	1.9 million lb
Primary Missions	Polar, LEO, and GEO
Compatible Upper Stages	IUS and Centaur
First Launch	14 June 1989
Success/Flight Total	5/5
Launch Sites	CCAFS: SLC–40 and 41 (28.5° N, 81.0° W) VAFB: SLC–4E (34.7° N, 120.6° W)
Launch Azimuths	CCAFS: 93°–112° VAFB: 147°–210°
Estimated Launch Price	TIV/NUS: $154 million TIV/IUS: $214 million TIV/Centaur: $227 million

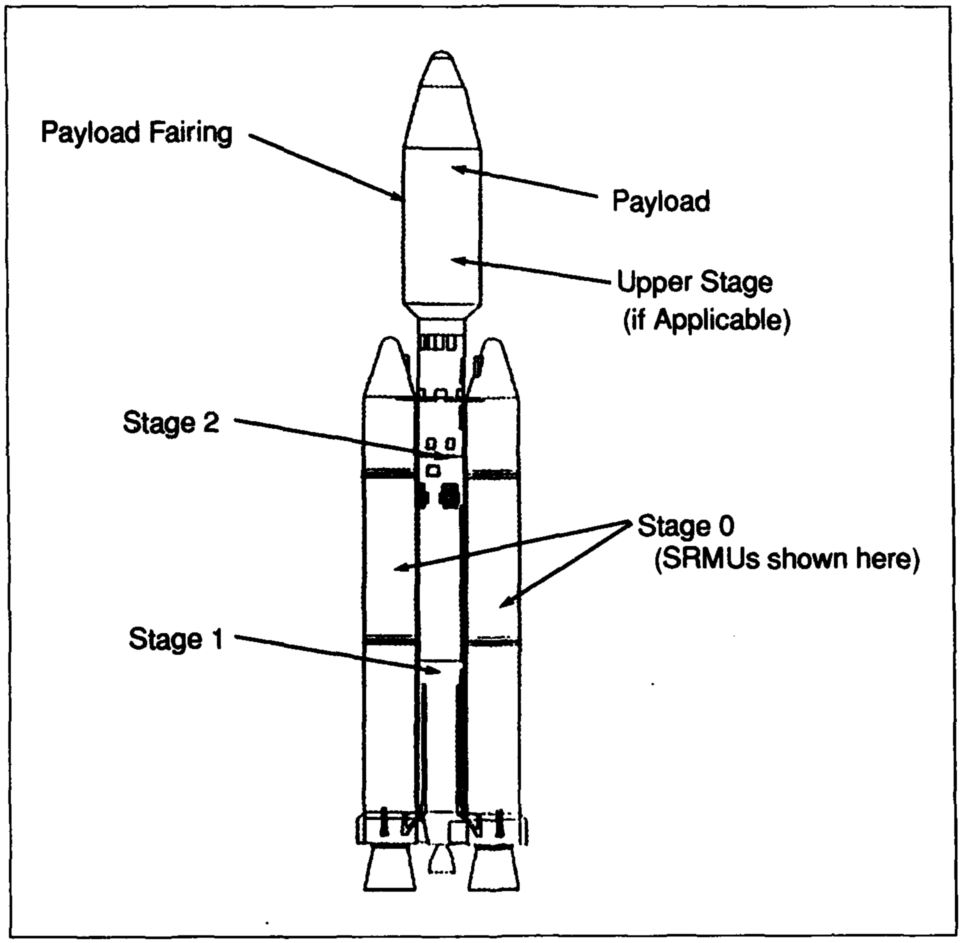

Figure B.1. Titan IV with Solid Rocket Motor Upgrade Boosters.

Table B.2. Titan IV Payload Capability from CCAFS (20:268 and 279).

Configuration or Parameter	Orbit	
	LEO*	**GEO****
TIV/SRM	39,000 lb	N/A
TIV/SRMU	47,700 lb	N/A
TIV/SRM/IUS	N/A	5,250 lb
TIV/SRM/Centaur	N/A	10,000 lb
TIV/SRMU/IUS	N/A	6,670 lb
TIV/SRMU/Centaur	N/A	12,700 lb***
Maximum Payload Diameter	15 ft	
Payload Fairing Size	Diameter: 16.7 ft Height: 56, 66, 76, and 86 ft	
Standard Orbit and Accuracy	Perigee: 60 ± 1.1 nm Apogee: 177 ± 4.4 nm Inclination: 28.6 ± 0.01 deg	

*110–nm circular Low Earth Orbit
**Geosynchronous Orbit
***However, the Centaur upper stage has a structural limitation of 11,500 lb.

Table B.3. Titan IV Historical Launch Information (15).

Date	Location	Launch Pad	Upper Stage	Configuration Number
14 Jun 89	CCAFS	SLC–41	IUS	SS-ELV-402
08 Jun 90	CCAFS	SLC–41	NUS	SS-ELV-405
12 Nov 90	CCAFS	SLC–41	IUS	SS-ELV-402
08 Mar 91	VAFB	SLC–4E	NUS	SS-ELV-403
07 Nov 91	VAFB	SLC–4E	NUS	SS-ELV-403

Table B.4. Titan IV Configuration Number Definitions (2:B-4).

Configuration Number	**Launch Location**	**Upper Stage**
SS-ELV-401	CCAFS	Centaur
SS-ELV-402	CCAFS	IUS
SS-ELV-403	VAFB	NUS
SS-ELV-404	VAFB	NUS with Titan Payload Adapter
SS-ELV-405	CCAFS	NUS

Table B.5. Titan IV Payload Fairing Characteristics (20:272).

Parameter	**TIV Payload Fairing**
Manufacturer	McDonnell Douglas Space Systems Co
Length	56, 66, 76, and 86 ft
Diameter	16.7 ft
Mass	11,000, 12,000, 13,000, and 14,000 lb
Sections	3
Structure	Isogrid
Material	Aluminum

Table B.6. Data for a Titan IV Typical Flight Sequence (20:278).

Time (min:sec)	**Events**	**Altitude (ft)**
00:00	Stage 0 Ignition	0
02:00	Stage 1 Ignition	158375
02:12	Stage 0 Separation	186398
03:50	Payload Fairing Separation	383614
05:08	Stage 2 Ignition	501535
05:09	Stage 1 Separation	502624
08:52	Stage 2 Shutdown	608391
09:18	Stage 2 Jettison	607604

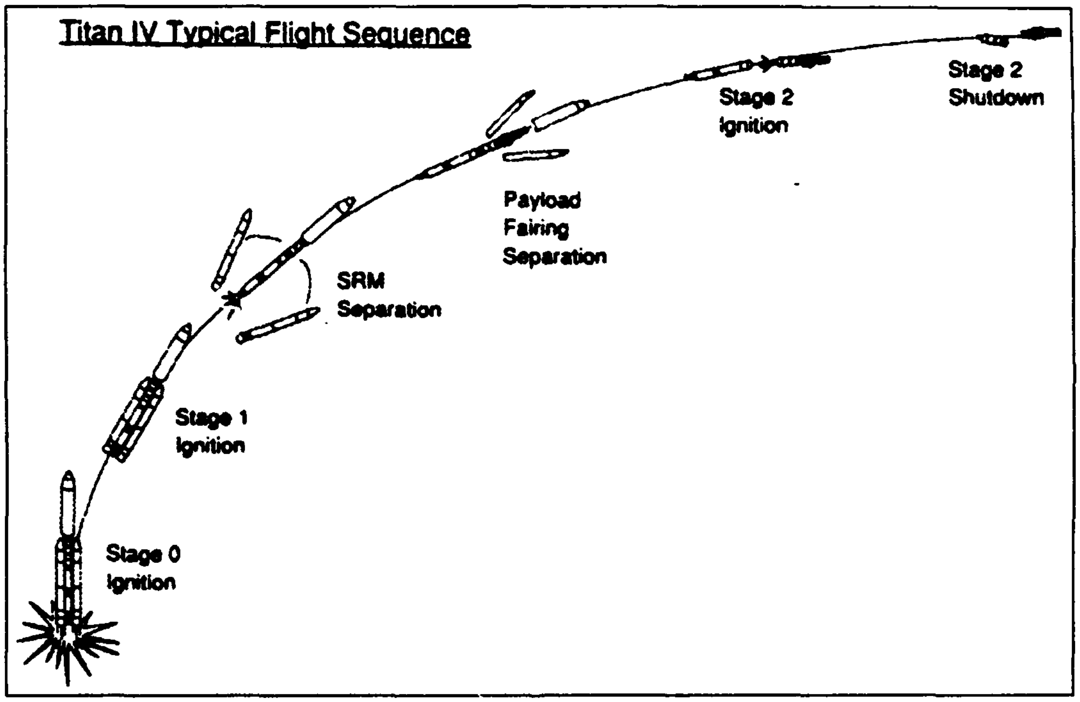

Figure B.2. Titan IV Typical Flight Sequence (20:278).

Appendix C. *Titan IV Launch Processing Data*

The information contained in Tables C.2, C.3, and C.4 of this appendix is the basis for the analysis of this thesis and the trade-off curves developed and presented in Chapter V. The information listed in Tables C.2 and C.4 was derived from a "Level-Seven Work Schedule" prepared by the Titan IV Launch Operations Planning branch of Martin Marietta Astronautics Group at Cape Canaveral Air Force Station on 15 May 1992 (29). This schedule shows the required activities of the generic launch processing flow for a Titan IV with Solid Rocket Motors (SRMs) and a Centaur upper stage.

Quattro Pro, a computer software spreadsheet program, was used to manipulate this information for the critical path determination and summations appearing at the end of each table. A legend for the symbols and abbreviations used in the tables of this chapter is presented as Table C.1.

Table C.1. Legend for Table Symbols and Abbreviations.

Symbol or Abbreviation	Meaning
Shifts	Shifts Required to Complete Activity
Type	Type of Activity
N/A	Not Applicable
A	Assembly Activity
T	Testing Activity
R	Trans-shipment Activity
Crit	Critical
Assy	Assembly Shifts
Test	Testing Shifts
Trans	Trans-shipment Shifts

C.1 Data for VIB Activities

Pertinent information from the Level-Seven schedule for generic Vertical Integration Building (VIB) processing is listed in Table C.2 with the type of activity, either assembly, testing, or trans-shipment, and whether that activity lies on the inferred critical path.

C.2 Data for SMAB Activities

Information obtained from the Titan IV Program Control branch of Martin Marietta at CCAFS is the basis of Table C.3 (38). The SMAB activities on the top-level critical path and their type are listed. A Level-Seven schedule of SMAB activities was not available.

C.3 Data for Launch Pad Activities

Pertinent information from the Level-Seven schedule for generic launch pad processing for a Titan IV with SRMs and a Centaur upper stage is listed in Table C.4 with the type of activity and whether that activity lies on the inferred critical path.

Table C.2. Data for Generic VIB Processing (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
1	**XPTR ACTIVITIES**	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
2	JCWS SANDBLAST/MARTYTE	N/A	30	A	No	1.000	0	30	0	0	0	0	0
3	XPTR TO VIB	5M75	1	R	No	1.000	0	0	0	1	0	0	0
4	JCWS MARTYTE 108 LVL	JCWS	12	A	No	1.000	0	12	0	0	0	0	0
5	UMBILICAL INSTL	6G50	7	A	No	1.000	0	7	0	0	0	0	0
6	TRANSORB C/O	6G50	1	T	No	1.000	0	0	1	0	0	0	0
7	T&FS CMG CALS	4L50	2	T	No	1.000	0	0	2	0	0	0	0
8	ELECT XPTR REFURB	6G50	12	A	No	1.000	0	12	0	0	0	0	0
9	XPTR REFURB	5G80	9	A	No	1.000	0	9	0	0	0	0	0
10	ELECT SYS CALS	6L51	2	T	No	1.000	0	0	2	0	0	0	0
11	INSTL GRATING/CORE SUPPORTS	5B02	10	A	Yes	0.200	2	10	0	0	2	0	0
12	ELECT FAC CONNECTIONS	6M50	2	A	No	1.000	0	2	0	0	0	0	0
13	ELECT SYS FUNCT	6A51	2	T	No	1.000	0	0	2	0	0	0	0
14	BOATTAIL POSITIONING	5B02	1	A	Yes	1.000	1	1	0	0	1	0	0
15	PACE CKOUT	6M58	1	T	No	1.000	0	0	1	0	0	0	0
16	DCE CKOUT	7A80	2	T	No	1.000	0	0	2	0	0	0	0
17	INSTR VAN CKOUT	7A57	3	T	No	1.000	0	0	3	0	0	0	0
18	DTS FUNCT	7A79	2	T	No	1.000	0	0	2	0	0	0	0
19	LCA/VCA CKOUT	6M59	1	T	No	1.000	0	0	1	0	0	0	0
20	ELECT SYS FUNCT	6R55	10	T	No	1.000	0	0	10	0	0	0	0
21	**VEHICLE ACTIVITIES**	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
22	PACE APPLICATION SOFTWARE	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
23	MGC SOFTWARE O.D.	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
24	IMU SOFTWARE O.D.	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
25	TEST PARAMETER O.D.	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
26	TDP MCRS O.D.	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
27	CORE VEHICLE ON DOCK	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
28	STG II ENG SKIRT DYE PENT INSP	OSP 2.70	1	T	Yes	1.000	1	0	1	0	0	1	0
29	REMOVE TRANSPORT BREATHERS	8B01	1	R	No	1.000	0	0	0	1	0	0	0
30	OFFLOAD CV AND XPORT TO VIB	5B25	1	R	No	1.000	0	0	0	1	0	0	0
31	VEHICLE RECEIPT & INSPECT	5B26	1	T	Yes	1.000	1	0	1	0	0	1	0
32	STG II T&FS COMPONENT INSTL	4U02	10	A	No	1.000	0	10	0	0	0	0	0
33	XFER STG II TO ROTATION FIXTURE	5B26	1	A	Yes	1.000	1	1	0	0	1	0	0
34	REMOVE INTERSTAGE	5B26	1	A	No	1.000	0	1	0	0	0	0	0
35	RIG ACTUATORS	2L01	1	A	No	1.000	0	1	0	0	0	0	0
36	XFER STG I TO ROTATION FIXTURE	5B26	1	A	No	1.000	0	1	0	0	0	0	0
37	STG II ELECT COMP INSTL	6U02	30	A	Yes	1.000	30	30	0	0	30	0	0

Table C.2. Data for Generic VIB Processing (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
38	STG I ELECT COMP INSTL	6U01	30	A	No	1.000	0	30	0	0	0	0	0
39	STG I A/B COMPONENT INSTL	7U01	20	A	No	1.000	0	20	0	0	0	0	0
40	STG I T&FS COMPONENT INSTL	4U01	10	A	No	1.000	0	10	0	0	0	0	0
41	STG II A/B COMPONENT INSTL	7U02	18	A	No	1.000	0	18	0	0	0	0	0
42	STG I ENG INSTL	8U01	1	A	No	1.000	0	1	0	0	0	0	0
43	STG I HYD INSTL	2U01	12	A	No	1.000	0	12	0	0	0	0	0
44	STG II ENG INSTL	8U02	1	A	No	1.000	0	1	0	0	0	0	0
45	ABLATIVE SKIRT INST - STG II	OSP 3.4	1	A	No	1.000	0	1	0	0	0	0	0
46	STG II PROP INSTL	8U12	3	A	No	1.000	0	3	0	0	0	0	0
47	STG I PROP INSTL	8U11	3	A	No	1.000	0	3	0	0	0	0	0
48	STG II ENG RECV & INSP	OSP 1.16	1	T	No	1.000	0	0	1	0	0	0	0
49	STG I ENG RECV & INSP	OSP 1.15	1	T	No	1.000	0	0	1	0	0	0	0
50	STG II HYD INSTL	2U02	12	A	No	1.000	0	12	0	0	0	0	0
51	WEIGH STG I	5B27	1	T	No	1.000	0	0	1	0	0	0	0
52	WEIGH STG II	5B27	1	T	Yes	1.000	1	0	1	0	0	1	0
53	VEH ERECTION PREPS	5B02	2	A	Yes	1.000	2	2	0	0	2	0	0
54	ERECT STG I	5B02	1	A	Yes	1.000	1	1	0	0	1	0	0
55	ERECT STG II	5B02	1	A	Yes	1.000	1	1	0	0	1	0	0
56	ALIGN VEHICLE	5B31	1	A	Yes	1.000	1	1	0	0	1	0	0
57	OPEN VEHICLE	5B77	1	A	Yes	1.000	1	1	0	0	1	0	0
58	PROP SUCTION LINES INSTL STG II	8U14	2	A	No	1.000	0	2	0	0	0	0	0
59	IGS INSTL	3C10	1	A	Yes	1.000	1	1	0	0	1	0	0
60	ACTUATOR INCLINATION CK - STG I	2C41	1	T	No	1.000	0	0	1	0	0	0	0
61	PROPULSION RECV & INSP	8H10	1	T	No	1.000	0	0	1	0	0	0	0
62	PROGRAM & PATCHING	7A50	10	A	Yes	1.000	10	10	0	0	10	0	0
63	CONN INNER STG CONNECTORS	6C05	10	A	No	1.000	0	10	0	0	0	0	0
64	PARALLEL WIRING CKS	6C05	6	T	No	1.000	0	0	6	0	0	0	0
65	T&FS CSTSS INSTL & RF CKS	4C10	4	T	No	1.000	0	0	4	0	0	0	0
66	ROLL CONTROL ASSY & C/O	OSP 3.18	1	A	No	1.000	0	1	0	0	0	0	0
67	CONN/DISCONN ACTUATORS	2C25	1	A	No	1.000	0	1	0	0	0	0	0
68	APPLY VEHICLE AIR	11A01	1	A	No	1.000	0	1	0	0	0	0	0
69	STG II PROP INSTL	8U12	5	A	No	1.000	0	5	0	0	0	0	0
70	STG I PROP INSTL	8U11	2	A	No	1.000	0	2	0	0	0	0	0
71	PROP SUCTION LINES INSTL STG I	8U13	4	A	No	1.000	0	4	0	0	0	0	0
72	TRANSMITTER PRESS CK	7C02	1	T	No	1.000	0	0	1	0	0	0	0
73	CONN IGS	3C10	1	A	No	1.000	0	1	0	0	0	0	0
74	ULTRASONIC PRE-SCAN	8C05	1	T	Yes	1.000	1	0	1	0	0	1	0

Table C.2. Data for Generic VIB Processing (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
75	ESD CONNECTIONS - IGS	3C10	1	A	Yes	1.000	1	1	0	0	1	0	0
76	ESD CONNECTIONS	7U02	1	A	No	1.000	0	1	0	0	0	0	0
77	ESD CONNECTIONS	7U01	1	A	No	1.000	0	1	0	0	0	0	0
78	SINGLE POINT GROUND	6C05	1	T	Yes	1.000	1	0	1	0	0	1	0
79	INITIAL PRESS	8B01	1	T	No	1.000	0	0	1	0	0	0	0
80	POWER-ON OIR MTG	N/A	1	T	No	1.000	0	0	1	0	0	0	0
81	STG II PROP FUNCTL & LK CK	8C03	2	T	No	1.000	0	0	2	0	0	0	0
82	CONN STG I & II UMBILICALS	6C05	3	A	Yes	1.000	3	3	0	0	3	0	0
83	T&FS CSTSS CONNS	4C10	2	T	No	1.000	0	0	2	0	0	0	0
84	STG I PROP FUNCTL & LK CK	8C02	2	T	No	1.000	0	0	2	0	0	0	0
85	INSTL SRMS AND CONN	6C50	1	T	Yes	1.000	1	0	1	0	0	1	0
86	SRM/CORE ELEC I/F	6C15	1	T	No	1.000	0	0	1	0	0	0	0
87	POWER-ON READINESS REVIEW MTG	N/A	1	T	No	1.000	0	0	1	0	0	0	0
88	CORE VEHICLE POWER ON	6C14	1	T	No	1.000	0	0	1	0	0	0	0
89	ENGINE TORQUE VERIF - STG I	OSP 3.23.1	2	T	Yes	1.000	2	0	2	0	0	2	0
90	RMIS CKOUT	7C07	1	T	No	1.000	0	0	1	0	0	0	0
91	A/B INSTR SYS CKOUT (N-I-B)	7C06	8	T	Yes	1.000	8	0	8	0	0	8	0
92	ENGINE TORQUE VERIF - STG II	OSP 3.24.1	2	T	No	1.000	0	0	2	0	0	0	0
93	STG I ENG INSTR	OSP 6.1-6.5	1	A	No	1.000	0	1	0	0	0	0	0
94	STG II LOW PT DRAIN & G/B PRESS LINE INSTL	OSP 3.14	1	A	No	1.000	0	1	0	0	0	0	0
95	STG I LOW PT DRAIN & G/B PRESS LINE INSTL	OSP 3.13	1	A	No	1.000	0	1	0	0	0	0	0
96	STG II ENG INSTR	OSP 6.2-6.6	1	A	No	1.000	0	1	0	0	0	0	0
97	TURBO PUMP SERVICE	OSP 3.23	2	A	No	1.000	0	2	0	0	0	0	0
98	SERVICE STG II HYDS	2C07	4	A	Yes	1.000	4	4	0	0	4	0	0
99	ACTUATOR INCLINATION CK - STG II	2C41	1	T	No	1.000	0	0	1	0	0	0	0
100	HEAT SHIELD INSTL	8C01	2	A	No	1.000	0	2	0	0	0	0	0
101	TURBO PUMP SERVICE	OSP 3.24	1	A	No	1.000	0	1	0	0	0	0	0
102	SERVICE STG I HYDS	2C06	4	A	Yes	1.000	4	4	0	0	4	0	0
103	ENG ELECT CONTROL SERVICE - STG II	OSP 3.24.2	1	A	No	1.000	0	1	0	0	0	0	0
104	ENG ELECT MANUAL CK - STG II	OSP 3.16	1	T	No	1.000	0	0	1	0	0	0	0
105	ABLATIVE SKIRT INSTL - STG I	OSP 3.3	2	A	No	1.000	0	2	0	0	0	0	0
106	IGS IMPEDANCE & BUS XFER	6C02	10	T	Yes	1.000	10	0	10	0	0	10	0
107	TCV FUNCT CK - STG II	OSP 3.24.4	1	T	No	1.000	0	0	1	0	0	0	0
108	COMBINED SYS ENG LK CK - STG II	OSP 3.22	3	T	No	1.000	0	0	3	0	0	0	0
109	PSVOR POSITION VERIF. - STG II	OSP 3.42	1	T	No	1.000	0	0	1	0	0	0	0

Table C.2. Data for Generic VIB Processing (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
110	T&FS PREFUNCTL	4C04	1	T	No	1.000	0	0	1	0	0	0	0
111	A/B INSTR AGC CALS	7C06	1	T	No	1.000	0	0	1	0	0	0	0
112	T&FS AGC CALS	4C03	1	T	No	1.000	0	0	1	0	0	0	0
113	ENG ELECT CONTROL SERVICE - STG I	OSP 3.23.2	1	A	No	1.000	0	1	0	0	0	0	0
114	ENG ELECT MANUAL CK - STG I	OSP 3.15	1	T	No	1.000	0	0	1	0	0	0	0
115	T&FS REDUNDANT CIR CKS	4C13	1	T	No	1.000	0	0	1	0	0	0	0
116	TCV FUNCTL CK - STG I	OSP 3.23.4	2	T	No	1.000	0	0	2	0	0	0	0
117	IGS CKOUT	3C51	1	T	Yes	1.000	1	0	1	0	0	1	0
118	PULSE BEACON FUNCTL	4C08	1	T	No	1.000	0	0	1	0	0	0	0
119	IGS I/F CKS	3C10	1	T	No	1.000	0	0	1	0	0	0	0
120	PSVOR POSITION VERIF CK - STG I	OSP 3.41	1	T	No	1.000	0	0	1	0	0	0	0
121	A/B INSTR TM CALS	7C06	2	T	Yes	1.000	2	0	2	0	0	2	0
122	FLIGHT CONTROL SYS CKOUT	2C03	2	T	No	1.000	0	0	2	0	0	0	0
123	COMBINED SYS ENGINE LK CK - STG I	OSP 3.21	4	T	No	1.000	0	0	4	0	0	0	0
124	PLF CST PREPS	6C22	18	T	Yes	1.000	18	0	18	0	0	18	0
125	ELEC CST PREPS	6D01	15	T	No	1.000	0	0	15	0	0	0	0
126	RF SYSTEM CKOUT	7C09	1	T	No	1.000	0	0	1	0	0	0	0
127	AVV	2C09	1	T	No	1.000	0	0	1	0	0	0	0
128	TCPS CKT VERIFICATION	OSP 3.23.3	1	T	No	1.000	0	0	1	0	0	0	0
129	ATC ELECT I/F	6C18	1	T	No	1.000	0	0	1	0	0	0	0
130	BLACK SHIRT MTG	N/A	5	T	No	1.000	0	0	5	0	0	0	0
131	RF XMISSION MODE	7M15	4	T	No	1.000	0	0	4	0	0	0	0
132	T&FS CST PREPS	4D02	5	T	No	1.000	0	0	5	0	0	0	0
133	GIE CST PREPS	7D50	4	T	No	1.000	0	0	4	0	0	0	0
134	ENG CST PREPS	OSP 3.19	1	T	No	1.000	0	0	1	0	0	0	0
135	PROP CST PREPS	8D31	1	T	No	1.000	0	0	1	0	0	0	0
136	DISCRETE VERIFICATION	0D07	1	T	No	1.000	0	0	1	0	0	0	0
137	IGS CST SUPPORT	3D02	1	T	No	1.000	0	0	1	0	0	0	0
138	VIB CST	0D01	1	T	No	1.000	0	0	1	0	0	0	0
139	IGS CST SUPPORT	03D01	1	T	No	1.000	0	0	1	0	0	0	0
140	T&FS CST SECURING	4D02	2	T	Yes	1.000	2	0	2	0	0	2	0
141	DATA REVIEW	0M01	1	T	No	1.000	0	0	1	0	0	0	0
142	DATA REVIEW/DATA GO	0D01	1	T	No	1.000	0	0	1	0	0	0	0
143	ELECT CST SECURING	6D01	3	T	No	1.000	0	0	3	0	0	0	0
144	SRM CORE MATE RR MTG	N/A	1	A	No	1.000	0	1	0	0	0	0	0
145	IGS LIGHTNING PROTECTION	3M03	1	R	No	1.000	0	0	0	1	0	0	0

Table C.2. Data for Generic VIB Processing (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
146	ELECT REDUNDANT CIR CKS	6D02	1	T	No	1.000	0	0	1	0	0	0	0
147	SECURE SRM SIMULATOR	6C50	1	T	Yes	1.000	1	0	1	0	0	1	0
148	CLEAN SRM UMBILS	6C15	1	T	No	1.000	0	0	1	0	0	0	0
149	FACILITY DISCONNS	6M50	1	R	Yes	1.000	1	0	0	1	0	0	1
150	MOVE TO SMAB	5C77	1	R	Yes	1.000	1	0	0	1	0	0	1
			Shift Sum				Crit Sum	Assy Sum	Test Sum	Trans Sum	Assy Crit Sum	Test Crit Sum	Trans Crit Sum
			495				115	310	179	6	63	50	2

Table C.3. SMAB Data (35).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
N/A	**SMAB ACTIVITIES**	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
N/A	CV/SRM MATE	N/A	5	A	Yes	1.000	5	5	0	0	5	0	0
N/A	MOVE CV/SRM TO PAD	N/A	1	R	Yes	1.000	1	0	0	1	0	0	1
			Shift Sum				Crit Sum	Assy Sum	Test Sum	Trans Sum	Assy Crit Sum	Test Crit Sum	Trans Crit Sum
			6				6	5	0	1	5	0	1

Table C.4. Data for Generic Centaur Pad Flow (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
N/A	**LAUNCH PAD ACTIVITIES**	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
1	PREP FOR SRM B/U	N/A	1	A	No	1.000	0	1	0	0	0	0	0
2	PREP FOR SRM B/U	N/A	1	A	No	1.000	0	1	0	0	0	0	0
3	SET LV ON PAD	5B79	1	A	No	1.000	0	1	0	0	0	0	0
4	START PAD PREPS	5C77	1	A	No	1.000	0	1	0	0	0	0	0
5	MISC MECH OPS	5C77	4	A	No	1.000	0	4	0	0	0	0	0
6	MST/UT OPERATIONS	5M80	4	A	Yes	1.000	4	4	0	0	4	0	0
7	VAN A/C SETUP	11M53	1	A	No	1.000	0	1	0	0	0	0	0
8	VAN/FAC ELECT CONN	6M50	1	A	No	1.000	0	1	0	0	0	0	0
9	INSTL PLATFORM SAFETY NETS	5C77	3	A	No	1.000	0	3	0	0	0	0	0
10	SRM B/U #6 NORTH (TWR CL)	61JBB	1	A	No	1.000	0	1	0	0	0	0	0
11	SRM B/U #6 SOUTH (TWR CL)	6AJBB	1	A	No	1.000	0	1	0	0	0	0	0
12	MOVE & POSITION RR CARS	13M60	3	A	No	1.000	0	3	0	0	0	0	0
13	SRM B/U #7 NORTH (TWR CL)	61JBB	1	A	No	1.000	0	1	0	0	0	0	0
14	SRM B/U #7 SOUTH (TWR CL)	61JBB	1	A	No	1.000	0	1	0	0	0	0	0
15	SRM B/U FWD SEC NORTH (TWR CL)	61JBB	1	A	No	1.000	0	1	0	0	0	0	0
16	SRM B/U FWD SEC SOUTH (TWR CL)	61JBB	1	A	No	1.000	0	1	0	0	0	0	0
17	L/L C/O & ADJUST ISCS (DAILY THRU ILC)	LL-7000	2	T	No	1.000	0	0	2	0	0	0	0
18	(USI) UES CLEANING	USAF	3	A	Yes	0.333	1	3	0	0	1	0	0
19	PACE C/O	6M58	1	T	No	1.000	0	0	1	0	0	0	0
20	GROUND INSTR SYS C/O	7A57	4	T	No	1.000	0	0	4	0	0	0	0
21	GROUND STA C/O	7A50	4	T	No	1.000	0	0	4	0	0	0	0
22	INSTL SRM JOINT SHIMS	61JBU	4	A	Yes	1.000	4	4	0	0	4	0	0
23	SQIB SIMULATOR TEST & CAL	NET-7003	6	T	No	1.000	0	0	6	0	0	0	0
24	DTS C/O	7A79	4	T	No	1.000	0	0	4	0	0	0	0
25	DCE C/O	7A80	4	T	No	1.000	0	0	4	0	0	0	0
26	MATE OUTRIGGER TO SRMS	5C77	2	A	Yes	0.500	1	2	0	0	1	0	0
27	L/L TRANSDUCER VERIFY	LL-7005	20	T	No	1.000	0	0	20	0	0	0	0
28	PROP PAD CHECKS	8C04	4	T	No	1.000	0	0	4	0	0	0	0
29	L/L MUX SYSTEM OPERATIONS (DAILY THRU ILC)	LL-7001	2	T	No	1.000	0	0	2	0	0	0	0
30	L/L SYSTEM PROGRAMMING	LL-7004	8	T	No	1.000	0	0	8	0	0	0	0
31	VEHICLE ACCESS PREPS	5C77	3	A	Yes	1.000	3	3	0	0	3	0	0
32	ALIGN VEHICLE	5C77	1	A	No	1.000	0	1	0	0	0	0	0
33	LH2 CONTROLLER ADJUST & C/O	NET-7007	1	T	No	1.000	0	0	1	0	0	0	0
34	VEHICLE A/C SETUP	11A01	1	A	No	1.000	0	1	0	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
35	CENTAUR MATE PREPS	9B35	2	A	No	1.000	0	2	0	0	0	0	0
36	CLEAN COMPARTMENT 2A	5C77	3	A	No	1.000	0	3	0	0	0	0	0
37	TVC LEAK CKS	61LAR	3	T	No	1.000	0	0	3	0	0	0	0
38	R/W CABLE INSTL	61JBO	3	A	Yes	0.667	2	3	0	0	2	0	0
39	CORE VEHICLE/CENTAUR MATE RR	N/A	1	A	No	1.000	0	1	0	0	0	0	0
40	LO2 CONTROLLER ADJUST & C/O	NET-7008	1	T	No	1.000	0	0	1	0	0	0	0
41	HOIST CENTAUR (TWR CLEAR)	9B35	1	A	No	1.000	0	1	0	0	0	0	0
42	XPORT/ERECT CENTAUR	STRU-7011	1	A	No	1.000	0	1	0	0	0	0	0
43	ISOLATE/CLEAN LVL 10	USAF	1	A	No	1.000	0	1	0	0	0	0	0
44	CLEAN LVL 11-14	N/A	2	A	Yes	1.000	2	2	0	0	2	0	0
45	UPPER STAGE MECH MATE	9B35	1	A	No	1.000	0	1	0	0	0	0	0
46	PRESSURE CHANGEOVER	PNEU-7007	1	A	No	1.000	0	1	0	0	0	0	0
47	CENTAUR TANKWATCH (CONTINUOUS)	PNEU-7009	0	T	No	1.000	0	0	0	0	0	0	0
48	CENTAUR SUPPORT OPERATIONS	STRU-7021	2	A	No	1.000	0	2	0	0	0	0	0
49	APPLY CENTAUR STRETCH	PNEU-7007	1	A	No	1.000	0	1	0	0	0	0	0
50	SRM HEATER INSTL	61JBT	6	A	No	1.000	0	6	0	0	0	0	0
51	UES CLEANING (48 HOURS)	N/A	5	A	Yes	1.000	5	5	0	0	5	0	0
52	CDF INSTL	OSP 3.37.1	2	A	No	1.000	0	2	0	0	0	0	0
53	REMOVE BASE PLF DOORS	9B35	2	A	No	1.000	0	2	0	0	0	0	0
54	PLATFORM CONFIG LVL 10	N/A	1	A	No	1.000	0	1	0	0	0	0	0
55	UNBAG BASE PLF	9B35	1	A	No	1.000	0	1	0	0	0	0	0
56	ELECT/CHUTE INSP/INSTL	STRU-7008	1	A	No	1.000	0	1	0	0	0	0	0
57	CONNECT ECS	ECS-7000	1	A	No	1.000	0	1	0	0	0	0	0
58	CV/US ELECT MATE	6C22	2	A	No	1.000	0	2	0	0	0	0	0
59	FTS SET C/O	FTS-7000	2	T	No	1.000	0	0	2	0	0	0	0
60	C-BAND PRESS/LEAK CHECK	RF-7001	2	T	No	1.000	0	0	2	0	0	0	0
61	INSTL IRU/SCU/SEU/DCU/SIU	N/A	2	A	No	1.000	0	2	0	0	0	0	0
62	CCET PREPS/SV SIM ELECT MATE	NET-7035	4	T	Yes	1.000	4	0	4	0	0	4	0
63	FILL & DRAIN VALVE INSTL	PLS-7001	4	A	No	1.000	0	4	0	0	0	0	0
64	T&FS RF SYSTEM C/O	4C16	2	T	No	1.000	0	0	2	0	0	0	0
65	RMTS SET UP	64SDM	1	T	No	1.000	0	0	1	0	0	0	0
66	RF CHECKS	4C10	2	T	No	1.000	0	0	2	0	0	0	0
67	A/B INSTR RF SYS C/O	7C22	2	T	No	1.000	0	0	2	0	0	0	0
68	FLUIDS UMB/CHUTE INSTL	STRU-7008	2	A	No	1.000	0	2	0	0	0	0	0
69	R/W CABLE INSTL	61JBO	3	A	Yes	0.667	2	3	0	0	2	0	0
70	CCET	NET-7035	1	T	No	1.000	0	0	1	0	0	0	0
71	SCU C/O	NET-7035	1	T	No	1.000	0	0	1	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
72	IMG FINAL ALIGN (NO VEH MOTION)	NET-7035	1	T	No	1.000	0	0	1	0	0	0	0
73	PU FUNCTIONAL	NET-7035	1	T	No	1.000	0	0	1	0	0	0	0
74	DCU FUNCTIONAL	DCU-7000	1	T	No	1.000	0	0	1	0	0	0	0
75	ELECT FUNCT & END CAP LK CKS (CL LVL3 & BE)	61KAT	1	T	No	1.000	0	0	1	0	0	0	0
76	INSTALL CSTSS	4C10	2	T	No	1.000	0	0	2	0	0	0	0
77	PLATE EJECT C/O & CHUTE INSTL	PNEU-7008	4	A	Yes	0.250	1	4	0	0	1	0	0
78	UMBILICAL RETRACT SYSTEM C/O	RET-7001/700	12	T	No	1.000	0	0	12	0	0	0	0
79	CRITICAL CIRCUIT CKS	61KBF	3	T	Yes	0.333	1	0	3	0	0	1	0
80	CORE UMBILICAL MATE	6C14	1	A	No	1.000	0	1	0	0	0	0	0
81	VEHICLE/AGL CLEANING/INSP	STRU-7000	1	A	No	1.000	0	1	0	0	0	0	0
82	CCET DATA REVIEW	NET-7035	2	T	No	1.000	0	0	2	0	0	0	0
83	THRUST SECTION TV SYSTEM	TV-7000	3	A	No	1.000	0	3	0	0	0	0	0
84	ABN ECS DUCTING C/O	STRU-7002	3	T	No	1.000	0	0	3	0	0	0	0
85	ABN INSTR MEAS	TLM-7002	9	T	No	1.000	0	0	9	0	0	0	0
86	TLM XDUCER C/O	TLM-7005	12	T	No	1.000	0	0	12	0	0	0	0
87	ROLL CONTROL NOZZLE TORQUE CK	OSP 3.24.3	1	T	No	1.000	0	0	1	0	0	0	0
88	STG I TPA TORQUE	OSP 3.11	1	T	No	1.000	0	0	1	0	0	0	0
89	STG II TPA TORQUE	OSP 3.12	1	T	No	1.000	0	0	1	0	0	0	0
90	LHE LINE INSULATION	PROP-7006	4	A	Yes	0.750	3	4	0	0	3	0	0
91	UMB RETRACT LANYARD INSTL	RET-7003	7	A	Yes	0.429	3	7	0	0	3	0	0
92	R/W COVER INSTL	61JCA	3	A	No	1.000	0	3	0	0	0	0	0
93	LHE DISCONN LEAK CHECK	PROP-7001	6	T	No	1.000	0	0	6	0	0	0	0
94	DISCONNECT RMTS	61SDM	1	T	No	1.000	0	0	1	0	0	0	0
95	FTS REC SENSITIVITY CHECKS	FTS-7001	1	T	No	1.000	0	0	1	0	0	0	0
96	LO2 AND LH2 INDICATOR CONTROL	NET-7005	1	A	No	1.000	0	1	0	0	0	0	0
97	FLIGHT CONTROL C/O	RF-7004	1	T	No	1.000	0	0	1	0	0	0	0
98	INSTR XDUCER INSTL (DAILY)	PLNG CARD	1	A	No	1.000	0	1	0	0	0	0	0
99	IMG CALIBRATION (NO VEH MOTION)	IMG-7000	2	A	No	1.000	0	2	0	0	0	0	0
100	S-BAND, SYSTEM C/O	RF-7005	2	T	No	1.000	0	0	2	0	0	0	0
101	FTS SENSITIVITY CKS	FTS-7002	1	T	No	1.000	0	0	1	0	0	0	0
102	LH2 BLANKET PURGE SYSTEM C/O	PNEU-7011	3	T	No	1.000	0	0	3	0	0	0	0
103	WIDEBAND INSTR SYS C/O	TLM-7009	3	T	No	1.000	0	0	3	0	0	0	0
104	CENTAUR PRESSURE C/O	PNEU-7010	8	T	No	1.000	0	0	8	0	0	0	0
105	STG II ENG DECAY CKS	OSP 3.22.2	2	T	No	1.000	0	0	2	0	0	0	0
106	DESTRUCT R/W INSTL	61JBR	1	A	No	1.000	0	1	0	0	0	0	0
107	TOWER CLEARED FOR ORD INSTL	61JBR	1	A	No	1.000	0	1	0	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
108	CENT HELIUM C/O	PNEU-7013	6	T	No	1.000	0	0	6	0	0	0	0
109	ABN HYD	HYD-7000	2	A	No	1.000	0	2	0	0	0	0	0
110	FLT CONT C/O	FC-7002	2	T	No	1.000	0	0	2	0	0	0	0
111	SRM INTEGRITIES	61LAH	1	T	No	1.000	0	0	1	0	0	0	0
112	FTS C/O	FTS-7003	1	T	No	1.000	0	0	1	0	0	0	0
113	STG I ENG LEAK CKS	OSP 3.21.2	2	T	No	1.000	0	0	2	0	0	0	0
114	SRM/CORE ELECT MATE	6C15	2	A	Yes	1.000	2	2	0	0	2	0	0
115	SRM CSTSS CONN	4C10	2	T	No	1.000	0	0	2	0	0	0	0
116	RADIATION SHIELD INSTL	STRU-7006	28	A	No	1.000	0	28	0	0	0	0	0
117	CV POWER ON	6C14	2	T	No	1.000	0	0	2	0	0	0	0
118	REFRESIL INSTL	8C01-IT	3	A	Yes	1.000	3	3	0	0	3	0	0
119	C-BAND SYSTEM C/O	RF-7000	2	T	No	1.000	0	0	2	0	0	0	0
120	P&W LEAK & FUNCT	PROP-7001	6	T	Yes	0.500	3	0	6	0	0	3	0
121	CENTAUR PURGE SYSTEM C/O	PNEU-7011	4	T	No	1.000	0	0	4	0	0	0	0
122	INSTR CAL & C/O	7C06	2	T	No	1.000	0	0	2	0	0	0	0
123	INSTRUMENTATION CALIBRATION	61LCC	1	T	No	1.000	0	0	1	0	0	0	0
124	LH2 STORAGE TANK FILL (AS REQUIRED)	LH2-7000	1	A	No	1.000	0	1	0	0	0	0	0
125	T&FS FUNCTIONAL	4C04	1	T	No	1.000	0	0	1	0	0	0	0
126	VEH/AGE INSP/CLEANING	STRU-7000	1	A	No	1.000	0	1	0	0	0	0	0
127	LO2 TANK FILL (AS REQD)	LO2-7000	1	A	No	1.000	0	1	0	0	0	0	0
128	LH2 SYSTEM C/O	LH2-7001	2	T	No	1.000	0	0	2	0	0	0	0
129	TCD INSTR. SYSTEM C/O	TLM-7008	10	T	No	1.000	0	0	10	0	0	0	0
130	ACTIVATE BATTERIES FOR FED	NET-7014	6	T	No	1.000	0	0	6	0	0	0	0
131	COMMAND REC ASC CALS	4C03	1	T	Yes	1.000	1	0	1	0	0	1	0
132	FTS OPEN LOOP	FTS-7004	1	T	No	1.000	0	0	1	0	0	0	0
133	T&FS OPEN LOOP C/O	4C05	1	T	No	1.000	0	0	1	0	0	0	0
134	GUIDANCE C/O (NO VEH MOTION)	3C51	2	T	No	1.000	0	0	2	0	0	0	0
135	STG I ENGINE WRAP	OSP 3.107.1	4	A	Yes	1.000	4	4	0	0	4	0	0
136	CENTAUR PURGE & SAMPLE DEWPOINTS	PNEU-7017	2	T	No	1.000	0	0	2	0	0	0	0
137	ECS C/O	ECS-7000	2	T	No	1.000	0	0	2	0	0	0	0
138	LO2 SYS C/O	LO2-7001	2	T	No	1.000	0	0	2	0	0	0	0
139	LO2 STORAGE TANK FILL (S.E. QUAD CLEAR)	LO2-7000	1	A	No	1.000	0	1	0	0	0	0	0
140	TELEMETRY X-MITTER C/O	7C09	1	T	No	1.000	0	0	1	0	0	0	0
141	CONN ACTUATORS	2C25	1	T	No	1.000	0	0	1	0	0	0	0
142	AVV	2C09	1	T	No	1.000	0	0	1	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
143	REMOVE STRETCH FOR AVV	PNEU-7007	1	T	No	1.000	0	0	1	0	0	0	0
144	SRM PHASING	3C13	1	T	No	1.000	0	0	1	0	0	0	0
145	PLIS CONTROLLER C/O	NET-7007	1	T	No	1.000	0	0	1	0	0	0	0
146	REAPPLY STRETCH	PNEU-7007	1	T	No	1.000	0	0	1	0	0	0	0
147	B/L CST OIR	N/A	1	T	No	1.000	0	0	1	0	0	0	0
148	STG I & II ENG CST PREPS	OSP 3.19	1	T	No	1.000	0	0	1	0	0	0	0
149	P/L CST PREPS	9C02	3	T	No	1.000	0	0	3	0	0	0	0
150	ELECT CST PREPS	6D01	5	T	No	1.000	0	0	5	0	0	0	0
151	T&FS CST PREPS	4D02	5	T	No	1.000	0	0	5	0	0	0	0
152	MECH CST PREPS	5D70	2	T	No	1.000	0	0	2	0	0	0	0
153	DISCONNECT ACTUATORS	2C25	1	T	No	1.000	0	0	1	0	0	0	0
154	CENTAUR PNEU SYS READINESS	PNEU-7016	8	T	No	1.000	0	0	8	0	0	0	0
155	PLIS CONTROLLER C/O	NET-7008	1	T	No	1.000	0	0	1	0	0	0	0
156	CONNECT T/C I/F CONNECTORS	GDSS-XXX	1	A	No	1.000	0	1	0	0	0	0	0
157	VEH/AGE CLEAN INSP	STRU-7000	1	A	No	1.000	0	1	0	0	0	0	0
158	BATTERY INSTL	GDSS-XXX	1	T	No	1.000	0	0	1	0	0	0	0
159	GND INST CST PREPS	7D51	2	T	No	1.000	0	0	2	0	0	0	0
160	PROP CST PREPS	8D31	2	T	No	1.000	0	0	2	0	0	0	0
161	ENG WALKDOWN	0E04	1	T	No	1.000	0	0	1	0	0	0	0
162	RF CONFIG	7M15	1	T	No	1.000	0	0	1	0	0	0	0
163	FED PREPS	GDSS-XXX	2	T	No	1.000	0	0	2	0	0	0	0
164	CENTAUR PROP & HYDRAULIC READINESS	PROP-7003	14	T	Yes	0.857	12	0	14	0	0	12	0
165	MECHANICAL READINESS	MECH-7001	7	T	No	1.000	0	0	7	0	0	0	0
166	GUIDANCE CST SUPPORT	3D01	1	T	No	1.000	0	0	1	0	0	0	0
167	B/L CST	0D02	1	T	No	1.000	0	0	1	0	0	0	0
168	FED	GDSS-XXX	1	T	No	1.000	0	0	1	0	0	0	0
169	HYDRAULIC SYSTEM SUPPORT	HYD-7002	1	T	No	1.000	0	0	1	0	0	0	0
170	VACUUM C/O LO2 & LH2 PIPING	PLS-7000	1	A	No	1.000	0	1	0	0	0	0	0
171	FLUID SAMPLING (LO2,GN2,GHE)	MECH-7005	1	T	No	1.000	0	0	1	0	0	0	0
172	NAV PROGRAM/PARAMETERS TAPE OD	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
173	FLIGHT PARAMETERS TAPE OD	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
174	B/L CST DATA REVIEW	0D02	2	T	No	1.000	0	0	2	0	0	0	0
175	FED DATA REVIEW	GDSS-XXX	3	T	No	1.000	0	0	3	0	0	0	0
176	SECURE RACEWAY C/O	9CXX	11	T	No	1.000	0	0	11	0	0	0	0
177	CST/FED DATA GO	0D02	1	T	No	1.000	0	0	1	0	0	0	0
178	LHE DEWAR FILL	LHE-7000	1	A	No	1.000	0	1	0	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
179	HAZ GAS DETECT SYS	PNEU-7016	4	A	No	1.000	0	4	0	0	0	0	0
180	CENT PNEU SYSTEM READINESS DEWPOINTS	PNEU-7017	1	T	No	1.000	0	0	1	0	0	0	0
181	LH2 FLUID SAMPLING	MECH-7005	1	T	No	1.000	0	0	1	0	0	0	0
182	LH2 STORAGE TANK FILL	LH2-7000	1	A	No	1.000	0	1	0	0	0	0	0
183	GOAS ALIGNMENT (NO SHAKE)	GOAS-7000	1	T	No	1.000	0	0	1	0	0	0	0
184	STANDBY MAIN ENG PURGE SYS	PROP-7003	1	A	No	1.000	0	1	0	0	0	0	0
185	CENTAUR VEH PWR APPLIC	FC-7001	7	T	No	1.000	0	0	7	0	0	0	0
186	MECH CST SECURING	5D70	2	T	No	1.000	0	0	2	0	0	0	0
187	TCD PREPS	5C78	5	T	No	1.000	0	0	5	0	0	0	0
188	PLF CST SECURING	9C02	2	T	No	1.000	0	0	2	0	0	0	0
189	PROP CST SECURING	8D31	2	T	No	1.000	0	0	2	0	0	0	0
190	PROP CST SECURING	OSP 3.19	2	T	No	1.000	0	0	2	0	0	0	0
191	REMOVE BATTERIES	GDSS-904	1	T	No	1.000	0	0	1	0	0	0	0
192	ELECT CST SECURING	6E01	4	T	No	1.000	0	0	4	0	0	0	0
193	T&FS CST SECURING	4D02	4	T	No	1.000	0	0	4	0	0	0	0
194	VMTS REMOVAL	NET-7035	1	T	No	1.000	0	0	1	0	0	0	0
195	L/L SYSTEM READINESS	LL-7004	3	T	No	1.000	0	0	3	0	0	0	0
196	COMPLEX ELECT READINESS	NET-7015	1	T	No	1.000	0	0	1	0	0	0	0
197	AIRBORNE INSTR PREPS	TLM-7004	1	T	No	1.000	0	0	1	0	0	0	0
198	LH2 TRANSFER LINE PURGE	MECH-7001	2	A	No	1.000	0	2	0	0	0	0	0
199	RF CHECKS COMPLETE	RF-7008	1	T	No	1.000	0	0	1	0	0	0	0
200	SHUTDOWN/DESTRUCT	FTS-7005	1	A	No	1.000	0	1	0	0	0	0	0
201	SAI ARM SAFE TEST	FTS-7006	1	T	No	1.000	0	0	1	0	0	0	0
202	0F01 PREPS	0F01	4	T	No	1.000	0	0	4	0	0	0	0
203	CLOSEOUT FWD ADAPTER	STRU-7004	1	A	No	1.000	0	1	0	0	0	0	0
204	BOATTAIL CLOSEOUT	STRU-7004	1	A	No	1.000	0	1	0	0	0	0	0
205	START GHE STANDBY PURGE (INFLIGHT)	PNEU-7011	1	T	No	1.000	0	0	1	0	0	0	0
206	S-BAND TELEMETRY PREPS	MECH-7005	1	T	No	1.000	0	0	1	0	0	0	0
207	C-BAND SYSTEM PREPS	MECH-7000	1	T	No	1.000	0	0	1	0	0	0	0
208	HYDRAULIC SYS FLT READINESS	PROP-7003	1	T	No	1.000	0	0	1	0	0	0	0
209	REMOVE MID WORK PLATFORMS	9BXX	1	A	No	1.000	0	1	0	0	0	0	0
210	TOP OFF FAC HE STORAGE BOTTLES	MECH-7001	4	A	No	1.000	0	4	0	0	0	0	0
211	THRUST SECTION TV SYS	TV-7000	5	A	Yes	0.400	2	5	0	0	2	0	0
212	PRESS CHANGEOVER	PNEU-7019	1	A	No	1.000	0	1	0	0	0	0	0
213	REMOVE PLATFORM THRUST SECTION	STRU-7004	1	A	No	1.000	0	1	0	0	0	0	0
214	INSTALL BASE PLF DOORS	9B35	1	A	No	1.000	0	1	0	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
215	VEHICLE CLOSEOUT COMPLETE	5C78	1	A	No	1.000	0	1	0	0	0	0	0
216	INSTL GIMBAL LK TEST HDWE	PROP-7003	1	T	No	1.000	0	0	1	0	0	0	0
217	SECURE MST FOR MOVE	9M80	2	T	No	1.000	0	0	2	0	0	0	0
218	CORE TANK PRESSURIZATION	8F02	2	A	No	1.000	0	2	0	0	0	0	0
219	LHE STAGING DUCT INSTL	PROP-7003	2	A	No	1.000	0	2	0	0	0	0	0
220	CENTAUR THRUST SECT CLOSEOUT (12 HRS)	MECH-7001	2	A	No	1.000	0	2	0	0	0	0	0
221	THRUST SECT CCTV PREPS	MECH-7001	1	A	No	1.000	0	1	0	0	0	0	0
222	STANDBY ENGINE PURGE SECURE	PROP-7003	2	A	No	1.000	0	2	0	0	0	0	0
223	MAIN ENGINE PURGE FUNCT CK	PROP-7003	1	T	No	1.000	0	0	1	0	0	0	0
224	LANDLINE PREPS	MECH-7001	1	T	No	1.000	0	0	1	0	0	0	0
225	LANDLINE SYS CHECK	MECH-7001	1	T	No	1.000	0	0	1	0	0	0	0
226	ENABLE FLUIDS MONITOR LOOP TEST	MECH-7001	1	T	No	1.000	0	0	1	0	0	0	0
227	START CENTAUR BOTTLE HE CHARGE	MECH-7001	1	A	No	1.000	0	1	0	0	0	0	0
228	CCLS DISK CHECK SUM VERIFICATION	MECH-7001	1	T	No	1.000	0	0	1	0	0	0	0
229	VEHICLE CLOSEOUT COMPLETE	MECH-7000	1	A	No	1.000	0	1	0	0	0	0	0
230	TCD READINESS REVIEW	N/A	1	T	No	1.000	0	0	1	0	0	0	0
231	FLIGHT CONTROL INITIAL CHECKS	MECH-7001	1	T	No	1.000	0	0	1	0	0	0	0
232	IMG CAL (NO VEH MOTION)	IMG-7000	2	A	No	1.000	0	2	0	0	0	0	0
233	TCD PREPS	GDSS-XX3	2	T	Yes	0.500	1	0	2	0	0	1	0
234	MST MOVE PREPS	MEC-7006	1	T	No	1.000	0	0	1	0	0	0	0
235	MOVE MST TO PARK	5M80	1	T	No	1.000	0	0	1	0	0	0	0
236	TCD	0F01	1	T	No	1.000	0	0	1	0	0	0	0
237	0F01	0F01	2	T	No	1.000	0	0	2	0	0	0	0
238	TERMINAL COUNTDOWN DEMO	GDSS-XX3	2	T	No	1.000	0	0	2	0	0	0	0
239	CENT TANK PURGE & SAMPLE	PNEU-7017	1	T	Yes	1.000	1	0	1	0	0	1	0
240	MOVE MST TO SERVICE	5M80	1	T	Yes	1.000	1	0	1	0	0	1	0
241	CLOSE UES DOOR	9M80	1	A	No	1.000	0	1	0	0	0	0	0
242	CLEAN LVL10, LOWER PLTFMS, SEAL LVL 13	9B35	1	A	No	1.000	0	1	0	0	0	0	0
243	TCD DATA REVIEW	GDSS-XX3	4	T	No	1.000	0	0	4	0	0	0	0
244	CORE TANK PRESS SECURING	8F02	1	T	No	1.000	0	0	1	0	0	0	0
245	CLEAN LVL 13 REMOVE BASE PLF DOORS	9B35	1	A	No	1.000	0	1	0	0	0	0	0
246	PRESS CHANGEOVER	PNEU-7019	1	A	No	1.000	0	1	0	0	0	0	0
247	TCD SECURING	GDSS-XX3	2	T	Yes	1.000	2	0	2	0	0	2	0
248	REINSTALL INTERNAL PLATFORMS	STRU-7004	1	T	Yes	1.000	1	0	1	0	0	1	0
249	TLM SV INTERFACE CKS	STRU-7007	1	T	No	1.000	0	0	1	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
250	REMV PREPS, CENTAUR HARDCOVER & STRETCH ADAPTER	PNEU-7007	1	A	No	1.000	0	1	0	0	0	0	0
251	REMOVE STRETCH ADAPTERS/BAG CENTAUR	STRU-7000	1	A	Yes	1.000	1	1	0	0	1	0	0
252	OPEN UES DOORS	9M80	1	A	Yes	1.000	1	1	0	0	1	0	0
253	REMOVE CENTAUR HARDCOVER/STRETCH ADAPTER	9B35	1	A	No	1.000	0	1	0	0	0	0	0
254	INSTL FWD PLF IN UES	9B09	1	A	Yes	1.000	1	1	0	0	1	0	0
255	CLOSE UES DOORS	9M80	1	A	No	1.000	0	1	0	0	0	0	0
256	REMOVE SCU/SC MOUNTING TAPE	N/A	1	A	No	1.000	0	1	0	0	0	0	0
257	REMOVE BASE PLF DOORS	9B35	1	A	No	1.000	0	1	0	0	0	0	0
258	GDSS FWD ADAPTER C/O	N/A	2	T	No	1.000	0	0	2	0	0	0	0
259	RADIATION SHIELD INSTL	STRU-7006	2	A	Yes	1.000	2	2	0	0	2	0	0
260	ADAPTER MATE PREPS	9BXX	2	A	No	1.000	0	2	0	0	0	0	0
261	UES SET UP FOR SV	9CXX	4	A	No	1.000	0	4	0	0	0	0	0
262	SV AIR COND SET UP	9C08	4	A	No	1.000	0	4	0	0	0	0	0
263	STG I ENG DECAY CKS	OSP 3.21.1	2	T	No	1.000	0	0	2	0	0	0	0
264	PU PROBE RESISTANCE CHECKS	NET-7013	1	T	No	1.000	0	0	1	0	0	0	0
265	INSTALL SV ADAPTER	9CXX	1	A	No	1.000	0	1	0	0	0	0	0
266A	SV OPERATIONS (ASSEMBLY)	N/A	31	A	Yes	0.645	20	31	0	0	20	0	0
266B	SV OPERATIONS (TESTING)	N/A	31	T	Yes	0.645	20	0	31	0	0	20	0
267	CLEAN UES	9CXX	4	A	No	1.000	0	4	0	0	0	0	0
268	STG I CLOSURES	OSP 3.37	4	A	No	1.000	0	4	0	0	0	0	0
269	STG I START CART INSTL	OSP 3.47	2	A	No	1.000	0	2	0	0	0	0	0
270	STG II START CART INSTL	OSP 3.48	2	A	No	1.000	0	2	0	0	0	0	0
271	TET, HAT, & HAR ACTIVITIES	N/A	9	T	No	1.000	0	0	9	0	0	0	0
272	PTPS GUAGE CAL	8L60	2	T	No	1.000	0	0	2	0	0	0	0
273	IGS NAV RUN (NO VEH MOTION)	3C12	2	T	No	1.000	0	0	2	0	0	0	0
274	IMG CAL	IMG-7000	2	T	No	1.000	0	0	2	0	0	0	0
275	OXID SYSTEM FUNCTIONAL	8E55	10	T	No	1.000	0	0	10	0	0	0	0
276	INSTALL BOATTAIL	8C01-40/41	3	A	No	1.000	0	3	0	0	0	0	0
277	BABCOCK RELAY RES CKS	6C03	2	T	No	1.000	0	0	2	0	0	0	0
278	ATC ELECT I/F	6C18	4	A	No	1.000	0	4	0	0	0	0	0
279	TCPS CHECKS	OSP 3.23.3	4	T	No	1.000	0	0	4	0	0	0	0
280	XRAY HYD PUMPS	2C40	1	T	No	1.000	0	0	1	0	0	0	0
281	FUEL SYSTEM FUNCTIONAL	8E52	10	T	No	1.000	0	0	10	0	0	0	0
282	TANKING PREPS	N2H4-7001	3	A	No	1.000	0	3	0	0	0	0	0
283	PLF CST PREP	9C02	6	T	No	1.000	0	0	6	0	0	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
284	PROPL CST PREP	8D31	6	T	No	1.000	0	0	6	0	0	0	0
285	ENG CST PREP	OSP 3.19	6	T	No	1.000	0	0	6	0	0	0	0
286	MECH CST PREP	5D70	6	T	No	1.000	0	0	6	0	0	0	0
287	T&FS INTEGRITY	4D02	6	T	No	1.000	0	0	6	0	0	0	0
288	A/B INSTR INTEGRITY	7D02	6	T	No	1.000	0	0	6	0	0	0	0
289	ELECT INTEGRITY	6D01	6	T	No	1.000	0	0	6	0	0	0	0
290	FLT CONT INTEGRITY	2D04	6	T	No	1.000	0	0	6	0	0	0	0
291	PLF CST PREP	9C02	6	T	No	1.000	0	0	6	0	0	0	0
292	N2H4 SAMPLING	N2H4-7001	1	T	No	1.000	0	0	1	0	0	0	0
293	CENTAUR TANKING	N2H4-7001	1	A	No	1.000	0	1	0	0	0	0	0
294	N2H4 SECURING	N2H4-7001	1	A	No	1.000	0	1	0	0	0	0	0
295	STG I GEARBOX PRESS INSTR	OSP 3.81	1	A	No	1.000	0	1	0	0	0	0	0
296	LO2 & LH2 C/O	PLS-7000	2	T	No	1.000	0	0	2	0	0	0	0
297	ASSEMBLE FWD PLF	9B09	8	A	No	1.000	0	8	0	0	0	0	0
298	PROPULSION INTEGRITY	8H10	4	T	No	1.000	0	0	4	0	0	0	0
299	STG I & II ENG. INTEGRITY	OSP 2.1/2.2	3	T	No	1.000	0	0	3	0	0	0	0
300	PROPL CST PREP	8D31	3	T	No	1.000	0	0	3	0	0	0	0
301	ENG CST PREP	OSP 3.19	3	T	No	1.000	0	0	3	0	0	0	0
302	INSTALL CSTSS SET	6D01	3	T	No	1.000	0	0	3	0	0	0	0
303	CONNECT ACTUATORS	2C25	1	A	No	1.000	0	1	0	0	0	0	0
304	DISCRETE VERIFICATION TEST	0D07	2	T	No	1.000	0	0	2	0	0	0	0
305	CERT PREPS	GDSS-XX2	4	T	No	1.000	0	0	4	0	0	0	0
306	LIGHTNING BASELINE	0H24	2	T	No	1.000	0	0	2	0	0	0	0
307	IVV FLIGHT PARAMETERS OD	N/A	0	N/A	No	1.000	0	0	0	0	0	0	0
308	ENG WALKDOWN	0E04	1	T	No	1.000	0	0	1	0	0	0	0
309	LCST READINESS REVIEW	N/A	1	T	No	1.000	0	0	1	0	0	0	0
310	AVV (LOCAL HAZ)	2C09	1	T	No	1.000	0	0	1	0	0	0	0
311	CST SETUP	7D51	1	T	No	1.000	0	0	1	0	0	0	0
312	CST SUPPORT	3D01	1	T	No	1.000	0	0	1	0	0	0	0
313	BLACK SHIRT MTG	N/A	8	T	No	1.000	0	0	8	0	0	0	0
314	R-COUNT	0E02	27	T	No	1.000	0	0	27	0	0	0	0
315	LAUNCH CST/CERT	0D01	2	T	Yes	1.000	2	0	2	0	0	2	0
316	CERT	GDSS-804	2	T	No	1.000	0	0	2	0	0	0	0
317	DATA GO/SECURING	0D01/0E02	2	T	Yes	1.000	2	0	2	0	0	2	0
318	CREW REST DAY (IF REQ'D)	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
319	ORD INSTL	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
320	WALKDOWN/LOAD PREPS	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0

Table C.4. Data for Generic Centaur Pad Flow (continued) (29).

#	Activity	Authorization	Shifts	Type	Crit Path	Crit Weight	Crit Sum	Assy	Test	Trans	Assy Crit	Test Crit	Trans Crit
321	OX LOAD	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
322	FUEL LOAD	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
323	ORD/BATT	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
324	2A DAY (IF REQUIRED)	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
325	ORD/T&FS SHUTDOWN/DESTRUCT	0E02	2	A	No	1.000	0	2	0	0	0	0	0
326	CORE PRESSURIZATION	0E02	2	A	Yes	1.000	2	2	0	0	2	0	0
327	LAUNCH READINESS REVIEW	0E02	2	T	No	1.000	0	0	2	0	0	0	0
328	ILC	0F02	0	N/A	No	1.000	0	0	0	0	0	0	0
			Shift Sum				Crit Sum	Assy Sum	Test Sum	Trans Sum	Assy Crit Sum	Test Crit Sum	Trans Crit Sum
			904				134	313	591	0	83	51	0

Bibliography

1. "AFSPACECOM Gains New Mission," *Space Trace: The Air Force Space Command Magazine*: 14–15 (July 1990).

2. Air Force Space Command Headquarters. *Air Force Space Command Operational Requirements Document (ORD) for the Upgraded Titan IV Space Launch System* (Draft). HQ AFSPACECOM/XPF: Peterson AFB, CO, 8 May 1992.

3. Air Force Space Command Headquarters. *Air Force Space Command System Operational Requirements Document (SORD) for Titan IV Space Launch System*, HQ AFSPACECOM/XPS: Peterson AFB, CO, 2 April 1991.

4. Augustine, Norman R., Chairman and Chief Executive Officer, Martin Marietta Corporation. "Defense Acquisition: The Tunnel at the End of the Light," Address to Air Force Institute of Technology students and faculty. Air Force Institute of Technology, Wright–Patterson AFB, OH, 15 October 1992.

5. Bradley, J. Timothy. "Phase Diagrams: A Top-Down Analysis Tool," *The Executive Analyst, 1*: 2–5. Reston, VA: STR Corporation, May 1986.

6. Defense Science Board. *1989 Summer Study on National Space Launch Strategy,* Prepared for the Office of the Under Secretary of Defense for Acquisition. Washington, D.C., March 1990 (AD–A222419).

7. Department of Defense. *Conduct of the Persian Gulf Conflict: An Interim Report to Congress.* Washington, D.C., July 1991.

8. Department of Defense. *Conduct of the Persian Gulf War: Final Report to Congress*, (Appendices A–S). Washington, D.C., April 1992 (AD–A249390).

9. Department of Defense. *Department of Defense Space Policy* (Unclassified). Washington D.C., 10 March 1987.

10. Department of Defense. *Soviet Military Power: Prospects for Change, 1989.* Washington, D.C., September 1989.

11. Department of the Air Force. *Air Force Operational Doctrine – – Space Operations,* Air Force Manual 2–25 (Draft). Washington D.C.: HQ USAF, 6 June 1990.

12. Ewing, Lee. "Space Program in Line for Overhaul," *Air Force Times, 53*: 30 (November 9, 1992).

13. Fallon, Marti E. Chief of Titan Spacelift Operations, HQ AFSPACECOM/DOS (Space Support), Peterson AFB, CO. Telephone interview. 31 August 1992.

14. Fallon, Marti E. Chief of Titan Spacelift Operations, HQ AFSPACECOM/DOPC (Space Support), Peterson AFB, CO. Facsimile message. 18 November 1992.

15. Folsom, Charles M. Titan Launch Controller, 45 OPG/LVO (Titan CTF), Cape Canaveral AFS, FL. Personal interview. 19 June 1992.

16. Folsom, Charles M. Titan Launch Controller, 45 OPG/LVO (Titan CTF), Cape Canaveral AFS, FL. Telephone interview. 22 September 1992.

17. Folsom, Charles M. Titan Launch Controller, 45 OPG/LVO (Titan CTF), Cape Canaveral AFS, FL. Telephone interview. 12 October 1992.

18. Goldratt, Eliyahu M. and Jeff Cox. *The Goal: A Process of Ongoing Improvement* (Second Revised Edition). Croton-on-Hudson, NY: North River Press. 1992.

19. Hanley, Art. "Titan IV: Latest in a family of giants," *Aerospace America, 29*: 34–38 (July, 1991).

20. Isakowitz, Steven J. *International Reference Guide to Space Launch Systems,* (1991 edition). Washington, D.C.: American Institute of Aeronautics and Astronautics, 1991.

21. Johnson, Nicholas L. *The Soviet Year in Space: 1990.* Colorado Springs, CO: Teledyne Brown Engineering, February 1991.

22. Kiernan, Vincent. "Corroded Titan Boosters Delay Military Launch," *Space News, 3*: 1 and 28 (June 22–July 5, 1992).

23. Kiernan, Vincent. "Titan Motor Ready for Crucial Firing," *Space News, 3*: 1 and 20 (June 1–7, 1992).

24. Kolcum, Edward H. "Air Force, Contractors Predict Long Life for Heavy-Lift Vehicle," *Aviation Week & Space Technology, 131*: 32–34 (July 17, 1989).

25. Masko, David P. "New Boosters Provide Another Arm of Airpower," *Space Trace: The Air Force Space Command Magazine*: 8 (June 1992).

26. Meyer, Scott K. "Backing-In," *The Executive Analyst, 2*: 6–8. Reston, VA: STR Corporation, June 1987.

27. Meyer, Scott K. "Top-Down Analysis," *The Executive Analyst, 1*: 1–2 and 6. Reston, VA: STR Corporation, May 1986.

28. Meyer, Scott K. "Top-Down Modeling," *The Executive Analyst, 1*: 1–6. Reston, VA: STR Corporation, March 1987.

29. Titan IV Level-Seven Schedules, *Generic VIB Processing* and *Generic Centaur Pad Flow (SMAB).* Cape Canaveral AFS, FL: Martin Marietta Astronautics Group, Launch Operations Planning, 15 May 1992.

30. United States Congress, Office of Technology Assessment. *Reducing Launch Operations Costs: New Technologies and Practices*. OTA-TM-ISC-28. Washington, D.C.: U.S. Government Printing Office, September 1988.

31. Watts, Robert S. Former Chief of Titan Vehicles and Major Acquisition Contracts Division, Titan Systems Program Office, Los Angeles AFS, CA. Telephone interview. 3 September 1992.

32. Wilson, Glenn P. "Why Reusability is King," *Ad Astra, 3*: 3 (March/April 1991).

33. Winston, Wayne L. *Operations Research: Applications and Algorithms* (Second Edition). Boston: PWS-Kent Publishing Company, 1991.

34. Woolley, Michael G. *Reduced Flexibility in Processing Titan IV Space Launch Vehicles at Cape Canaveral Air Force Station,* Air Command and Staff College Report Number 88-2805. Maxwell AFB, AL, April 1988 (AD-A194908).

35. Wyatt, Danny C. Titan IV Payload Integration Engineer, Martin Marietta Astronautics Group, Cape Canaveral AFS, FL. Personal interview. 18 June 1992.

36. Wyatt, Danny C. Titan IV Payload Integration Engineer, Martin Marietta Astronautics Group, Cape Canaveral AFS, FL. Telephone interview. 31 July 1992.

37. Wyatt, Danny C. Titan IV Payload Integration Engineer, Martin Marietta Astronautics Group, Cape Canaveral AFS, FL. Telephone interview. 13 August 1992.

38. Wyatt, Danny C. Titan IV Payload Integration Engineer, Martin Marietta Astronautics Group, Cape Canaveral AFS, FL. Telephone interview. 3 October 1992.

Vita

Captain Michael Timothy (Tim) Dunn [redacted] After graduating from Arab High School in 1982, he attended The University of Alabama where he distinguished himself as Air Force ROTC Corps Commander and as an honor student in the School of Engineering. He earned a Bachelor of Science in Electrical Engineering in December, 1986. After attending Undergraduate Space Training (UST) at Lowry AFB, Colorado, Captain Dunn was assigned to the 2nd Satellite Control Squadron, Falcon AFB, Colorado in 1988. He performed Navigation Analyst duties for the Navstar Global Positioning System (GPS) satellite constellation first as a crewmember and then as a member of the unit Standardization/Evaluation branch. In May 1991 he entered the School of Engineering, Air Force Institute of Technology at Wright-Patterson AFB, Ohio as a member of the Graduate Space Operations (GSO) class. [redacted]

[redacted]

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1992	Master's Thesis

4. TITLE AND SUBTITLE

ANALYSIS OF TITAN IV LAUNCH RESPONSIVENESS

5. FUNDING NUMBERS

6. AUTHOR(S)

Michael T. Dunn, Captain, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology
Wright-Patterson AFB, OH 45433

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GSO/ENS/92D-05

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Captain Charles M. Folsom
45 OPG/LVO (Titan CTF)
Cape Canaveral AFS, FL 32925

10. SPONSORING MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This research investigates the feasibility of developing responsive space systems through responsive launch operations with the Titan IV, the only expendable heavy-lift launch vehicle in the United States inventory. A definition for responsive launch has not been firmly established by Air Force Space Command for this launch vehicle. For benchmark purposes, this study uses the responsive launch definition contained in the proposal request for the Medium Launch Vehicle III: launch vehicle ignition within 60 days of mission need notification. Titan IV launch processing at Cape Canaveral Air Force Station (CCAFS), Florida currently requires in excess of six months, rendering Titan IV launch operations non-responsive. A Top-Down analysis of Titan IV launch processing at CCAFS is conducted to expose those factors which contribute to its current total duration. The factors considered are the time required for the assembly, testing, and trans-shipment activities associated with Titan IV launch operations. Analysis of improvements in these activities estimates their effect on Titan IV responsiveness. This study indicates that a Titan IV responsive launch capability may be attainable with improvements in processing activities, with a new launch processing concept of pre-processing, or with a combination of both.

14. SUBJECT TERMS

Titan IV, Cape Canaveral AFS, Launch Operations, Launch Processing, Responsive Launch, Launch Vehicle, Expendable Launch Vehicle, Top-Down Analysis

15. NUMBER OF PAGES

104

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL